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SIGNIFICANCE OF DROPLET SIZE IN SPRAYING WITH INSECTICIDES

Droppstorlekens betydelse vid besprutning med insekticider

BY

MAGNUS GUSTAFSSON

Förord av J. Mühlow

MED SVENSK SAMMANFATTNING

With 22 Figures and 9 Tables

STOCKHOLM 1958

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Emil Kihlströms Tryckeri A.-B.
Stockholm 1958
570776

Förord

Den omfattande oljeväxtodlingen, som kom igång i Sverige under andra världskriget medförde snabbt en förökning av åtskilliga av oljeväxternas skadeinsekter, och bekämpningsåtgärder över stora arealer blev ett livsvillkor för denna odling. Efter världskrigets slut kom i snabb följd i handeln en hel rad nya typer av bekämpningsmedel och därigenom öppnades nya vägar för bekämpningsarbetet. Jämsides med denna utveckling av de kemiska bekämpningsmedlen steg emellertid även kraven på goda apparater för dessa medels spridning, och detta nödvändiggjorde i sin tur undersökningar över bl. a. medlens fysikaliska egenskaper. För undersökningar rörande de biologiska och tekniska problem, som utövar avgörande inflytande vid konstruktionen av sprutor för kemisk bekämpning av ogräs, svampsjukdomar och insekter tillsatte Jordbrukets Forskningsråd 1949 en kommitté och ställde medel till dess förfogande för sådana undersökningar. Sedermera har anslag från Exportmedelsfonden möjliggjort fortsatt forskning.

Sedan vissa grundläggande försök med spridarmunstycken och sprutor utförts i Ultuna av agronom Helge Hellqvist, igångsattes 1953 vid Statens växtskyddsanstalts filial i Åkarp laboratorieundersökningar av droppstorlekens inverkan på den biologiska effekten vid spridning av insekticider. Dessa försök påbörjades av lantmästare Göran Bråhammar. Under sommaren 1954 fortsattes undersökningarna av agronom Åke Hedén och 1955 av agronom Magnus Gustafsson, åt vilken även anförtrotts sammanställningen av resultaten till föreliggande meddelande.

Åkarp den 14 mars 1958

J. Mühlow

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A Synopsis of Earlier Droplet Size Investigations and Droplet Problems

As a basis for the following exposition it is necessary to give a short synopsis of the different methods of atomization of liquids and an account of the spraying process itself.

With regard to the size of the droplet, technical equipment and purposes, the following schematic classification is made for the application of the spray. It can be distributed as follows: 1. Very small droplets (great atomization of the liquid, aerosol) intended to be distributed in space (space spray), originally generated thermally but nowadays also purely mechanically. 2. Droplets larger than in aerosol intended for deposits on vegetation. They can be divided up into sub-groups a) comparatively small droplets for deposits on vegetation by means of a stream of air and generated by hydraulic pressure (spray blowers) or by means of air (mist blowers) b) somewhat larger droplets for deposits on vegetation without any additional air stream (the oldest and most common agricultural sprays).

Consequently, atomization of the liquid can take place in several ways: in areosols either thermally or mechanically, in some nozzles by means of air and finally hydraulically (with pressure on the liquid) which is the most usual way in agriculture in our country.

Nozzles with eddy chamber are one of the oldest and most common types. Here the liquid is brought to rotate and a hollow cone surrounded by a sheet of liquid is formed. The latter can be split up into drops in different ways: by forming a network or threads that break, or by its breaking at the edge. The size of the droplets will depend on the thickness of the sheet formed and its thickness, in its turn, is dependent on the construction of the nozzle, pressure, surface tension of the liquid, viscosity and external air (Fraser and Eisenklam 1953). The same thing applies to flat-spray nozzles which generate a fan-shaped sheet which is split up. The droplets in these types of nozzles are of many different sizes. A more uniform size is obtained if the liquid is allowed to form a thin film on a rotating disc and is split up at the edge of the disc. The droplet formation of these types of nozzles has been photographed and investigated by Fraser and Eisenklam (1953).

Atomization by means of a stream of air gives a more uniform size of droplet. Hoare (1952) gives a synopsis of the different types of nozzles and their principles.

Thus, since the distribution of droplet sizes (»drop spectrum») is very different in different types of nozzles, the medium size of droplet cannot serve to characterize atomization of the liquid. The medium size of droplet (the arithmetical mean), as is seen by the curves, will represent only a very small part of the volume and consequently no particular significance can be attached to it. As is apparent from the curves on the sizes of droplets in the following diagrams and figures, the volume distributes itself in different ways in relation to the classes of droplet size. The large droplets, even if they are comparatively small, will greatly influence the curve of the volume. The degree of atomization of the liquid can be expressed by the mass median diameter, MMD, that divides the total volume of the spray into two equal parts, one half with a larger size of droplet and the other with a smaller size of droplet than MMD (Brown 1951). The MMD is obtained by calculating the liquid volume for each class of droplet size in percentage of the total volume, and successively summing up these values and drawing them on to a curve againts growing sizes of droplets. The vertical line cutting the curve at 50% clearly shows the MMD. Another way of characterizing the size of the droplet is the Sauter mean diameter (SMD or Do), which is the mean diameter in μ of a droplet whose ratio between surface and volume is the same as that of the liquid sprayed. Courshee *et al.* (1954) show how to convert the MMD into theSMD.

In order to find out the significance of the different sizes of droplets it is advisable first to look more closely into the part the smallest droplets play i.e. the droplets in the aerosols. These are used in space spray in attacking flying insects; consequently the droplets must be kept floating in the air for a certain period of time and not be allowed to be deposited on the vegetation at once. A table from Brooks (1947) is reproduced showing the rate of sedimentation and drift in small droplets of water (Table 1).

LaMer *et al.* (1947), who have worked with droplets of an oil solution of DDT and who have investigated mortality in *Aedes aegypti* L. in stationary air containing droplets of different sizes, found, that when the size of droplet was increased from 0.11 to 11 μ, mortality increased 250 times owing to the increase in sedimentation which was proportional to D^2 (D= the particle diameter). Stokes' law can be applied to these small particles.

Latta *et al.* (1947) have worked on a similar investigation in a wind tunnel and here found the requisite amount of poison inversely proportional to D^2V (D = the droplet diameter in μ. V = Velocity) up to 300; above 10 μ and 3 M.P.H. (1.4 metres per second) it was independent of both.

The effect of the very small particles is obviously worse especially if their velocity is low, this being due to the fact that a smaller amount of poison is deposited on the insects. A stream of air carries them past the insects more easily. However, too large particles are unpracticable in this type of spraying (space spray), as they sediment too rapidly.

Table 1. The rate of sedimentation and wind drift in droplets of different sizes releazed at a height of 3.05 meters (10 feet).

(After Brooks 1947.) The Table is slightly abbreviated and translated to the metric system.

Droplet diameter μ	Charakter of droplet in nature	Terminal velocity cm/min	Time to fall 3.05 m, min	Distance carried by 1.35 m/sec wind, m
1		0.180 cm	1686	135156
5	sea fog	4.51 »	67.5	5471
10		18.09 »	16.9	1358
20		72.3 »	4.20	338
33	cloud	1.97 m	1.55	125
50		4.52 »	0.675	54
80		11.56 »	0.264	21
100	mist	16.78 »	0.1818	15
170		36.60 »	0.0833	6.7
200	drizzel	43.31 »	0.0704	5.7
290		60.85 »	0.0437	3.5

Brooks (1947) has investigated how droplets of different large sizes behave when they are carried along with a stream of air and hit an objekt. He placed a cylinder in a stream of air and investigated the amount of droplets that were deposited in different sizes of droplets and velocity. As an expression of this amount Brooks uses E_m (dynamic catch) wich is the percentage of fractional width of the air stream cleaned of droplets. (Fig. 1). As is seen from Brooks' curves higher velocity is required to catch the same amount of a smaller size of droplet. The diameter of the cylinder plays its part, too. Counted at a percentage most is caught by cylinders of small diameters. At a velocity of 4.5 m/sec. and a cylinder ⅛ inch diameter (0.32 cm) Em is 32% for the droplet size 10 μ, for 20 μ E_m = 65%, 40 μ E_m = 85% and 100 μ Em = 95%. Consequently even rather large droplets are not completely caught at this velocity.

Thus, Brooks', Latta's and LaMer's tests show, when applied to insecticides in the form of aerosols, that a certain optimum size of droplet should exist. For small droplets (under 10 μ) the effect becomes worse, whether they are meant to catch an insect at rest (they sediment very slowly) or one that is flying (instead of catching the insect they are diverted from their course and follow the stream of air). If the droplets are too large (over approx. 40 μ) they sediment too rapidly and no other effect is got than a contact action. In insecticides for instance against the tsetse fly Yeo (1954) found that the size of the droplet for space spray should lie between 10 and 30 μ. Wind of course has some influence as is apparent from the foregoing paragraphs. The optimum size of droplet also becomes dependent on the size of the insect ; for house-flies an optimum droplet size

of 22 μ has been reached whereas for mosquitoes it lies at 16 μ (YEOMAN *et al.* 1949).

The behaviour of the aerosols is of great interest even when spraying for droplet deposits on vegetation. In spraying with an aggregat where the droplets are carried with a stream of air (spray blowers and mist blowers) one can obviously, by adding air, work with smaller sizes of droplets than when without adding air and still get the same amount to be deposited on vegetation. This group, however, is most suitably treated together with the purely hydraulic sprayers.

The significance of the size of the droplet for coverage has been investigated by POTTS (1947) from which Table 2 is reproduced. Small droplets apparently give a better coverage. In addition to this, small droplets have another advantage. COURSHEE *et al.* (1954) reckon upon a certain effect round each small amount of substance deposited on leafage, a certain biocidal diameter. (d). If the surface covered by the substance is S. the relation between effective coverage and real coverage will be $\frac{(S + d)^2}{S^2}$, which reaches a greater value for a smaller size of droplet. In substances with a local gas effect, e.g. parathion and lindane preparations, one has such a biocidal zone round each droplet.

Table 2. Size and number of droplets per square millimeter in the distribution of 11 liters of liquid uniformly over 1 hectare. (1 gallon/acre.)

(After POTTS 1946. The Table slightly abbreviated.)

Diameter, μ	Volyme, μ^3	Number per mm^2
10	525	1 780
20	4 200	222
30	14 175	66
50	65 620	14.3
70	180 007	5.2
100	525 000	1.73
150	1 771 000	0.53
200	4 200 000	0.22
300	14 175 000	0.066

There are, however, many reasons that speak against the very small sizes of droplets. From what has previously been said it is clear that particles with a diameter of 10 μ sediment very slowly and drift becomes very great (Table 1). They must have high velocity for deposits on an insect or vegetation. (Fig. 1). YEOMAN and ROGERS (1953) have calculated the »stop distance», S, of the droplets i.e. the distance that the particles can cover if

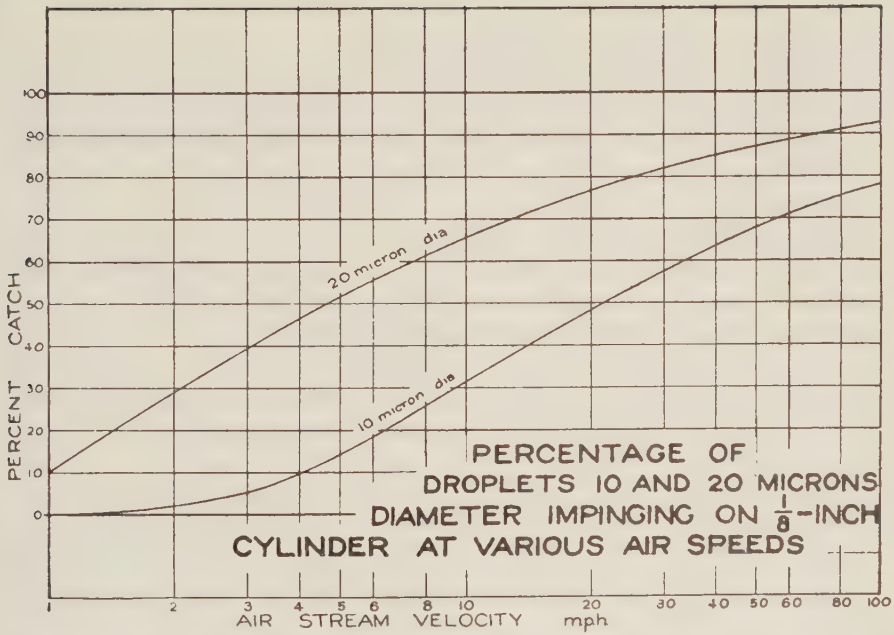


Fig. 1. Percentage of droplets deposited on a cylinder 0.32 cm in diameter at different wind velocities. (From Brooks 1947).

they are thrown out at a certain initial velocity into stationary air. If d = the diameter of the droplet in cm, p = density, V = the velocity in cm/sec, N = air viscosity in poises $S = \frac{d^2\,pV}{18\,N}$. A droplet with a diameter of 10 μ and an initial velocity of 5000 cm/sec in calm air (viscosity 1.8×10^{-4}) would go 1.54 cm, a droplet with a diameter of 50 μ 38.6 cm and a droplet with a diameter of 100 μ 1.54 m. In spraying, however, a stream of air arises that takes droplets along with it.

On the basis of laboratory tests Yeoman and Rogers (1953) arrive at the fact that lateral distribution becomes very great for a size of droplet under 50 μ MMD. They consider that the distance between the nozzle and the object sprayed should be such that at least 75% or more is deposited on the surface.

One way of making full use of the small droplets and their advantages is obviously to give them greater initial velocity by means of a stream of air as takes place on using a mist aggregate, for instance. However, consideration must be taken to evaporation and the greater sensitivity of a thin film to weather.

All sprays with additional air (spray blowers and mist blowers) give a

size of droplet larger than 40 μ MMD. Ripper (1955) states a MMD = 60 μ as applicable for this type of spray equipment.

For spraying withouth any additional air Brown (1951) considers that general experience in fields point to a droplet size of 80—30 μ being best. Potts (1946) also mentions the same sizes as being applicable in spraying with small quantities of liquid. He, however, gives no direct reasons for his point of view.

The disadvantage of too large droplets in using insecticides with a contact action is quite apparent and needs no further explanation. Coverage deteriorates and if droplet contains a larger quantity than a lethal dose the surplus amount is to no purpose. In laboratory tests with DDT Andersson (1948) has shown that with droplet sizes of 79, 178, 283, and 571 μ the effect on *Drosophila melanogaster* Mg. was inversely proportional to the size of droplet. A smaller quantity of DDT is required to cause the same mortality if the droplets are smaller.

Ripper (1955) considers that for hydraulic spraying without additional air, wind drift of all droplets smaller than 90 μ is risked. The nozzles that can give droplets above this droplet size give far too many large droplets, however, which of course impairs the effekt. Ripper considers that if the risk of wind drift is taken into consideration, field tests show that the largest quantity of droplets should lie between 90 μ and 160 μ with MMD = 130 μ. From statements made by Ripper (1955) it is apparent that in England the usual nozzles have far to wide a »drop spectrum» and to great a MMD. This will also hold good for nozzles in Sweden (which are of course partly the same).

For the judgement of sprays and their suitability it would be of great importance if, at the tests, it could be established:

a) what sizes of droplets can be obtained from the nozzles and other equipment
b) the width of the »droplet spectrum» (the distribution) and the mass median diameter, MMD.
c) the amount of substance that is deposited on vegetation in spraying.

The necessity of coverage is not so great in spraying with systemic insecticides, as the chemicals can move in the plant. With regard to wind drift Ripper (1955) is of the opinion that no droplets should be smaller than 100 μ at such a spraying.

Insecticides in Use

A survey of the insecticides used in the experiments is given in table 3. All insecticides employed in insecticidal experiments except nicotine are

Table 3. Survey of the insecticides employed in the experiments.

Insecticides	Amount of activ substance	Applied concentration, amount of insecticide and water	Surface tension, dynes/cm
DDT			
Ponocid F 25	26.5 % DDT,	1.4 l in 100 l/ha	
	21 % p,p¹-isomer	1.4 l in 500 l/ha	44.1 at 17.5°C
		2.0 l in 100 l/ha	43.9 at 17.5°C
		2.0 l in 500 l/ha	
Parathion			
Ewotox forte	45 % O,O-diethyl-O-p-nitrophenyl thiophosphate	⅓ l in 100 l/ha	37.4 at 20°C
		⅔ l in 100 l/ha	» » » »
		⅔ l in 500 l/ha	» » » »
Nicotine			
Weibulls Supernicotin 98 + 0.02 % Shellestol	98 % nicotine	0.25 l in 100 l/ha	42.0 at 18°C
		0.25 l in 500 l/ha	» » » »
		0.5 l in 100 l/ha	» » » »
		0.5 l in 500 l/ha	» » » »
		1.0 l in 100 l ha	» » » »
		1.0 l in 500 l/ha	» » » »
Organic phosphate with systemic action Systox	50 % O,O-diethyl-O- [2-(ethylmercapto) ethyl] thiophosphate	0.05 l in 100 l/ha	38.3 at 19°C

made up of emulsions. During the laboratory tests certain studies on these were also carried out.

Insecticides that are intended to be sprayed as emulsions as a rule contain emulsifiers as well as spreaders and stickers in addition to the active substance that can be dissolved in oil (direct or by means of an intermediary solvent). Unfortunately exact statements can seldom be obtained as to the composition of the commercial preparations.

In an emulsion the oil is divided into comparatively small droplets that keep themselves floating in the liquid without flowing together, thanks to its electric charge .The emulsifier is made up of long molecules with a hydrophil and a lipophil group and is concentrated in the interphase. In this way the droplets of emulsion are surrounded by an electric double layer. The charge of the droplets and consequently the stability of the emulsion is, therefore, influenced by the ions in the liquid and the pH value of the latter. (Brown and Hoskins 1939) i.e. the emulsion will be influenced by electrolytes and pH value of the water used in spraying. Fraser and Eisenklam (1953) show in their earlier mentioned investigations of the process of spraying that electrolytes influence decomposition of the liquid film formed by the nozzle, i.e. the droplet formation. In spraying with emulsions oil droplets serve as nuclei that produce holes in the liquid film. The size of the oil particles and consequently the formation of holes is changed

on adding salts. On adding 0.4% of NaCl hardly any film was formed at all. The emulsions employed in the experiments (Ponocid F25, Ewotox forte as well as many others, e.g. Toxidol) have, as was shown in photomicrography, comparatively large droplets, the greater part of noncolloidal dimensions. Systox emulsions, however, have small droplets compared with these and form a turbid colloidal solution, wich after some time, is transformed into a clear solution. If emulsions with large droplets are left to stand they then form »cream», if the oil is lighter than water; tar oils on the other hand sediment and form a bottom layer.

The size of the oil droplets diminishes in spraying, when they go through the nozzle; this is due to the construction of the nozzle and the amount of pressure. When the emulsion touches the surface of the plant the liquid droplet is flattened out and the oil droplets get into contact with the surface of the leafage. These spread much more easily than water and form a thin film on the surface of the plants. How easily the oil phase in this case gets into contact with the surface of the leafage (the emulsion breaks) depends among other things on the nature and amount of the emulsifier. Ben-Amotz and Hoskins (1937) has performed tests by adding partly a good wetting agent (albumin and haemoglobin) partly a good emulsifier (sodium oleate). On adding the wetting agent it was proved that a curve was got with a maximum for the amount of oil deposited on the leafage. Wetting increased the amount to a certain limit after which it decreased on account of the increased run-off. The addition of an emulsifier gave a decreased amount of oil on the leafage for increased amounts of emulsifier. Shepard (1955) states that Broder's tests show that the variation in the amount of oil remaining on the plant in commercial preparations depends to a great extent on the emulsifier.

The significance of the size of the emulsion droplets has been studied by Griffin *et al.* (1927) who has proved that for a great number of oils 10 μ large droplets are more effective than 2 μ against aphids. The amount of deposited oil increased with the size of the oil droplets. Brown (1951) means, however, that the size of the emulsion droplets in itself is not of any significance for the poisonousness. That would be determined by other qualities in the emulsion that influence the size of the droplet.

In spraying with an emulsion the effect must therefore be considered to be influenced by the qualities of the oil, the emulsifier, the wetting agent, the electrolytes present and the pH value in addition to the insecticide itself. The DDT compound employed in the following tests contains an oil that evaporates very slowly. On taking a photograph of the oil droplets on an object glass no decrease in their size could be seen after 28 hours. Crystallization could be seen as early as 1 hour after and was photographed. Between 23 and 28 hours after no great difference was seen and crystallization then appeared to be at least partly completed. By this it must probably

be understood that the intermediary solvent has evaporated and that crystallization has taken place in spite of the oil being there in apparently equally large droplets.

Parathion is in itself an oil-like substance which with the addition of an emulsifier can give an emulsion with water. The size and appearance of the emulsion droplets appear to be almost like those of the DDT emulsion when looking at them through a microscope. The volatility of this insecticide is comparatively small, the droplets from the emulsion remain on the surface of the leafage and are partly absorbed by the plant. Parathion, however, moves very slowly (by diffusion) in the plant and is inactivated rather rapidly (Frohberger 1949). It has a rather strong gas effect (Klimke and Haury 1950).

Systox gives much smaller droplets of emulsion (chiefly 1—2 μ and smaller) which are difficultly soluble in water. Volatility is comparatively great (150 times greater than in parathion). Like parathion it is an oil-like substance which together with an emulsifier (polyethylene glycolether) gives an emulsion. Penetration as well as movement in the plant have been investigated by means of radio-active phosphorus (Tietz 1954). After spraying or pencilling the plant 35—40% of the poison penetrated in one hour. 46% had evaporated after this time and the rest had remained on the leaves. The amount which is deposited and which penetrates depends on the ability of the solution to wet the leafage, the rapidity in drying and on the anatomical structure of the leafage. Systox is absorbed by the lipoidal soluble parts of the stomata cells and the basal cells of the hairs and penetration takes place fairly rapidly. It does not penetrate the stomata. The nerves of the leafage suppress distribution to a great extent. The poison can be conveyed with phloem and xylem. The effect of the poison on insects remains for 10—14 days.

Laboratory Tests with Different Sizes of Droplets

Methods for Determination of the Sizes of Droplets

In determining the size of the droplet in the nozzles employed at laboratory and field tests a modified method from Fuchs (1937) has been used. The droplets are caught on to an object glass covered with a coat of machine oil and vaseline. Instead of this mixture only oil (Shell's Valvata 85) of about the same viscosity as in Fuchs' mixture was used. Photographs of the droplets in a microscope could be taken rapidly owing to the greater transparency of this oil (time of exposure 1/10—1/20 sec). An orthochromatic film (Gevaert Duplo Orthofilm) was used.

In taking a photograph a checked net (with a distance of 95 μ between the lines) was placed in the ocular. The enlargement was approx. 64 times

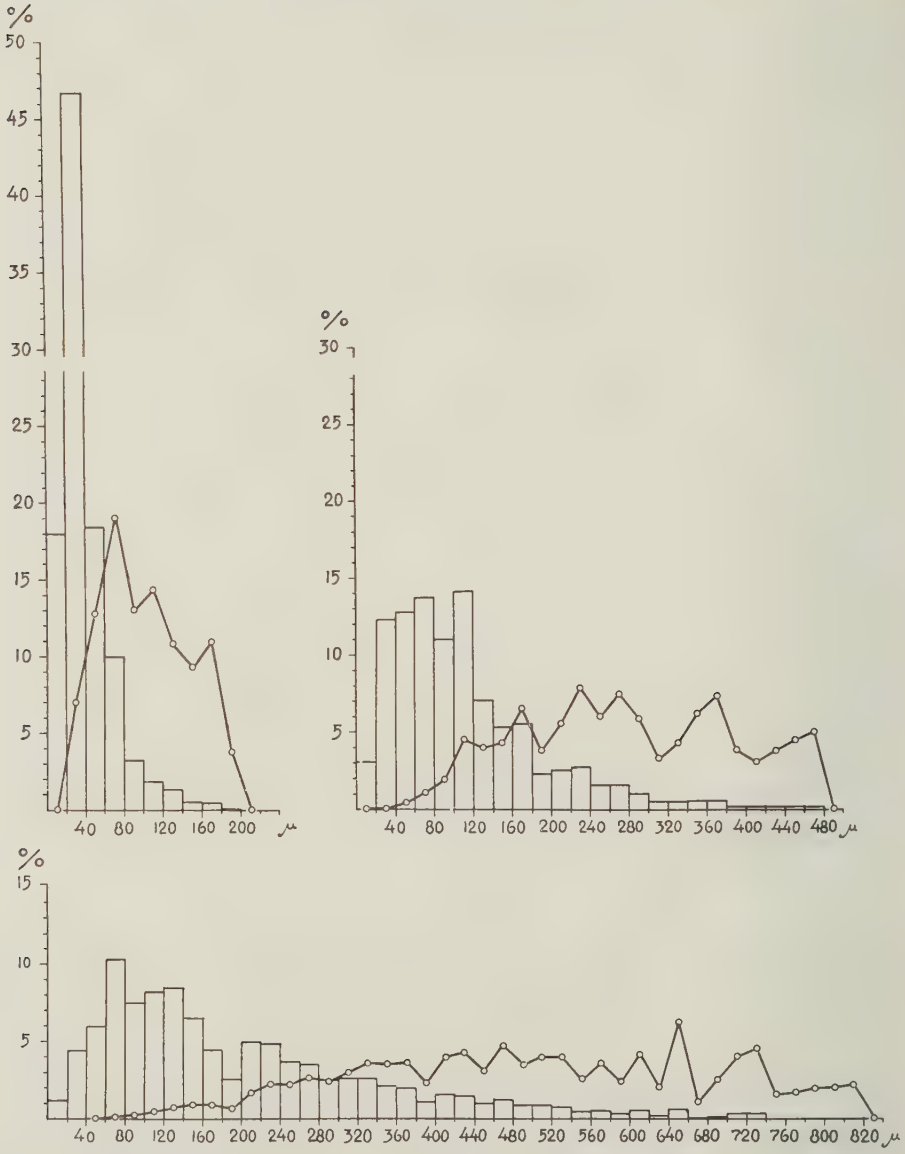


Fig. 2. Distribution of the sizes of droplets in the nozzles employed in the laboratory experiments. The staple diagrams indicate the percentage in number, the curve indicates the percentage of volume in different classes.

in large sizes of droplets, but in some cases it was less. This was determined with measuring oculars. The photographic negatives were projected by using a film picture projector on a screen where the droplets were measured. The

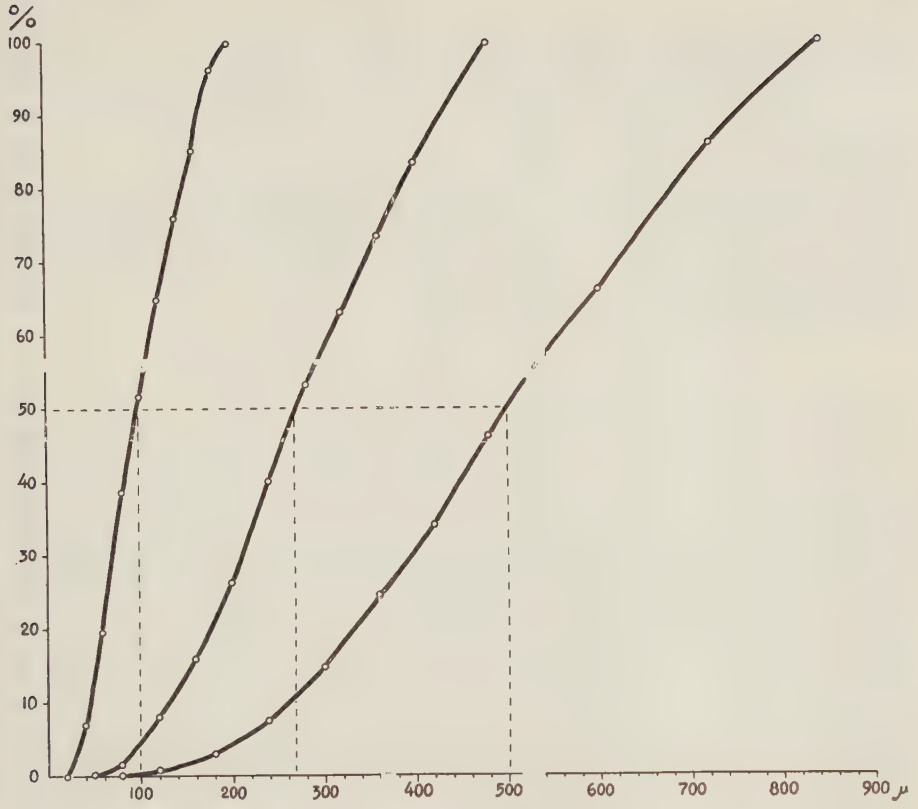


Fig. 3. Curves showing the sprayed volume's distribution of the different sizes of droplets in the three nozzles employed in the laboratory experiments. The dotted lines indicate the mass median diameter, MMD, for the three sizes of droplets. Se further in the text.

diameters of the droplets were rounded off to the the nearest number ending in 0 or 5, since greater precision could not be attained at the reading.

In order to vary the diameter of the opening of the nozzle there were different insets for the nozzle employed in the laboratory spray and different discs. By being able to vary the pressure, too, there were consequently quite a number of possibilities of combination. Different adjustments were tested and staple diagrams of the distribution of the droplets were drawn. Among these sizes of droplets three were chosen that could be considered suitable for testing at the following tests. 1000 droplets were measured for these adjustments and a staple diagram with 20 μ size class was drawn (see Fig. 2). On these there are also curves of the percentage of volume within the different classes.

A DDT emulsion with surface tension of 44.1 dynes/cm was used at

these three tests. The emulsions and solutions which have later been included in the tests have hade surface tensions of about this order of size.

The same mode of procedure was later used to determine the size of droplet and distribution of volume for the nozzles employed in field experiments.

The three adjustments which were then used in laboratory tests gave a medium size of droplet of 39.98 μ, 111.08 μ and 201.30 μ (arithmetical mean).

Curves in order to get the mass median diameter MMD have been drawn (Fig. 3). From these it is seen that MMD for the three sizes of droplets used at the laboratory tests is 100, 280 and 500 μ.

Methodics in Laboratory Experiments

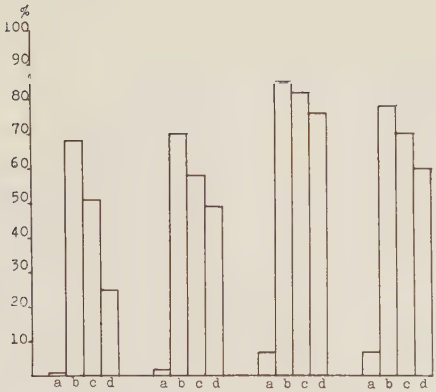
The laboratory tests were performed with a sprayer constructed for the purpose at Statens Maskinprovningar, Uppsala, and with droplet sizes of 100, 280, and 500 μ MMD. The sprayer was of the air-atomizer type of practically the same construction as that used in spraying experiments by Björling and Sellgren, who give a technical description and pictures of the sprayer and the nozzle in a recently published paper (1957). The adjustment of the amount of liquid was not very exact. Deviations up to 30 and 40 % of the desired amount of liquid take place in the smallest amount of liquid to be sprayed. (100 l/ha).

The amount of liquid sprayed was determined by placing a Petri dish with oil (viscosity S.A.E. 10) 53 cm under the nozzle and weighing it before and after the spraying. The plants to be experimented on were placed at the same distance from the nozzle.

As the size of the droplet is influenced among other things by surface tension, this was determined with a tensiometer. Table 3 gives the surface tension values of the insecticides employed, composition and the concentrations used at the tests. The differences in surface tension between the preparations employed are so small that they cannot have influenced the size of the droplet in any degree worth mentioning.

At the following tests 3 plants were as a rule sprayed with the same quantity of liquid and size of droplet and 3 untreated plants served as controls.

Counting has usually taken place after 20 hours when the number of dead + strongly influenced animals have been counted. The results are represented in a diagram where the percentage of dead + strongly influenced animals have been marked for the untreated control and the different sizes of droplets (marked a = untreated, b = 100 μ MMD, c = 280 μ and d = 500 μ MMD). Where several tests have been performed the average percentage has been calculated and reproduced. The results must be judged very carefully owing to the difficulty in getting a constant quantity of liquid



Insecticide l/ha	1,4	1,4	2	2
Water l/ha	100	500	100	500
Number of tests	2	2	3	3

Fig. 4. Laboratory experiments with DDT against rape beetle *(Meligethes aeneus* F.). The diagrams indicate the percentage of dead + greatly influenced animals. a = untreated, b = MMD 100 μ, c = MMD 270 μ, d = MMD 500 μ.

and on account of the small number of animals that have been able to be used on each plant.

The age of the experimental animals also influence the results. As has been seen by the tables mortality has in certain cases been rather great in the controls.

Experiments with DDT against Rape Beetle

Uniform-sized inflorescences of winter rape were employed for the tests. The leaves and blossoming flowers were removed and the stem of the inflorescence was stuck through a cork with a hole in it and then placed in a glass with water. Three plants to be experimented on were sprayed at a time and after drying the plants 20 rape beetles were placed on each plant. A lamp chimney with a piece of tulle stretched over it, was placed on top and the whole thing then put under a sodium vapour discharge lamp so that the animals might be active during the time of experiment.

On counting after 20 hours the number of dead and obviously greatly influenced animals was determined. The result is shown by the staple diagram Fig. 4 where the percentage of dead + greatly influenced animals has been marked. As will be seen all the tests show the greatest effect for the smallest size of droplet. There does not seem to be any difference in the effect between different quantities of liquid.

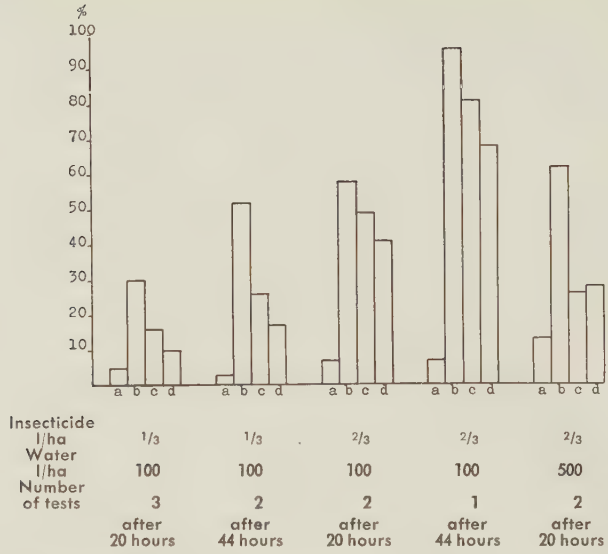


Fig. 5. Laboratory experiments with parathion against rape weevils. The diagrams indicate the percentage of dead + greatly influenced animals.
a = untreated, b = MMD 100 μ, c = MMD 270 μ, d = MMD 500 μ.

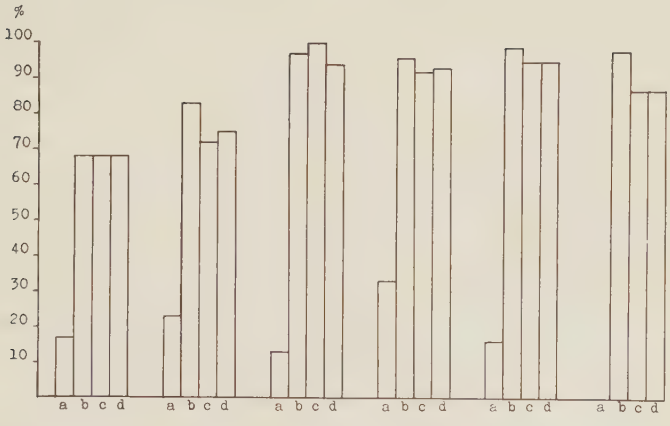
Experiments with Parathion against Rape Weevils

The methodics for these test was on the whole the same as for the DDT tests. In these experiments summer rape was employed and owing to the gas effect of the preparation net cages were placed over the plants instead of a lamp chimney. The number of animals was 20 per inflorescence and counting took place after 20 and 44 hours. The result of the tests is shown in a diagram Fig. 5.

The smallest size of droplet has throughout given the best result for the parathion preparation, too, whereas the amounts of liquid do not seem to have played any part.

Experiments with Nicotine against Aphids

Shoots with 2—3 leaves of chrysanthemum plants were used. 10 aphids *Brachycaudus helichrysi* Kalt. were transferred from infected leaves to each shoot and these were immediately sprayed and placed in a lamp chimney with a piece of tulle stretched over it under a sodium vapour discharge lamp. As at previous tests there were 3 parallels at each treatment as well as 3 controls. Counting took place after 20 hours. The number of dead and greatly influenced animals was determined and the animals that could not move were counted among the greatly influenced.



Insecticide l/ha	0,25	0,25	0,5	0,5	1	1
Water l/ha	100	500	100	500	100	500
Number of tests	2	1	1	1	2	2

Fig. 6. Laboratory experiments with nicotine against aphids (*Brachycaudus helichrysi* Kalt.) on chrysanthemum. The diagrams indicate the percentage of dead + greatly influenced animals.
a = untreated, b = MMD 100 μ, c = MMD 270 μ, d = MMD 500 μ.

No distinct difference between the different sizes of droplets or between the different quantities of liquids can be read from the results of the tests (see diagram Fig. 6).

Experiments with Systox against Aphids

Shoots of chrysanthemum were here used just as at the tests with nicotine and the number of animals (10) was the same. The same kind of aphid was used, too. The animals were placed on the sprayed plants after 1 day, 7 days and 14 days. Counting took place after 20 hours when the number of dead + greatly influenced insects was determined.

A similar test was performed with plants of winter rape and cabbage leaf aphids. The animals were here placed on plants after 1 day and after 5 days. Contrary to the DDT and parathion tests the largest size of droplet has had the best effect here (see Diagram Fig. 7).

Experiments with DDT against Grain Weevils

10×12 cm large pieces of planed wood were sprayed and dried after which 20 grain weevils were placed on them and a bowl was tipped over them. The number of dead + greatly influenced animals was counted after

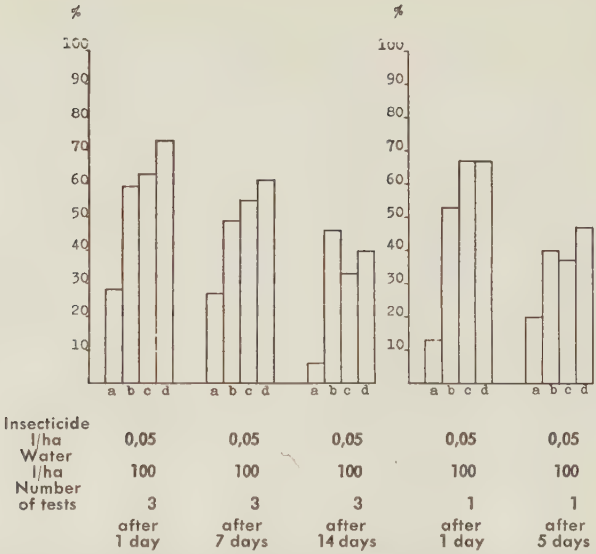


Fig. 7. Laboratory experiments with Systox against aphids. The first three diagrams *Brachycaudus helichrysi* Kalt. on chrysanthemum, the last diagrams, cabbage aphids *(Brevicoryne brassicae* L.) on rape. The diagrams indicate the percentage of dead + greatly influenced animals.

a = untreated, b = MMD 100 μ, c = MMD 270 μ, d = MMD 500 μ.

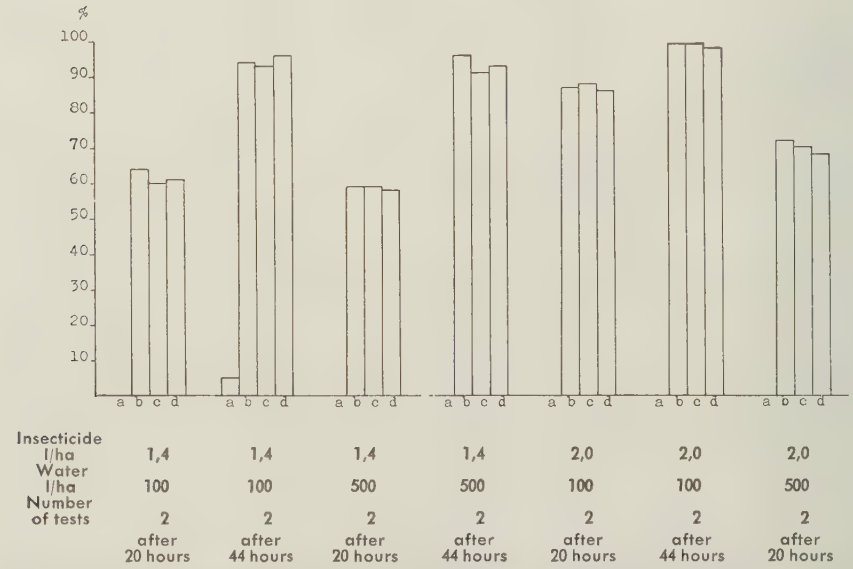


Fig. 8. Laboratory experiments with DDT against corn weevils *(Calandra granaria* L.). Sprayed on wooden plates. The diagrams indicate the percentage of dead + greatly influenced animals.

a = untreated, b = MMD 100 μ, c = MMD 270 μ, d = MMD 500 μ.

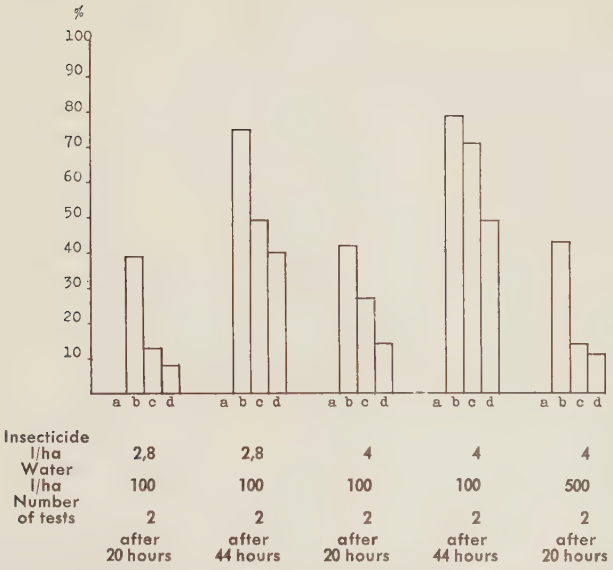


Fig. 9. Laboratory experiments with DDT against corn weevils *(Calandra granaria* L.). Spraying direct onto the animals. The diagrams indicate the percentage of dead + greatly influenced animals.
a = untreated, b = MMD 100 μ, c = MMD 270 μ, d = MMD 500 μ.

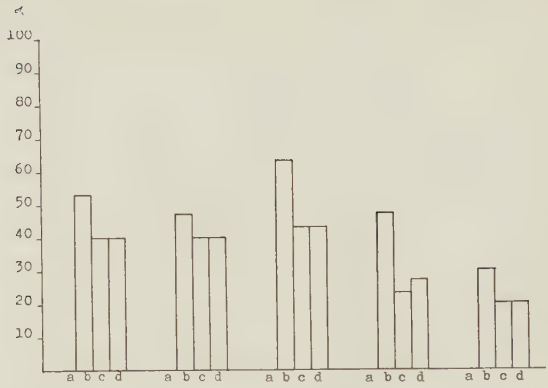
20 and 44 hours. The results indicate no difference in the effect between the different sizes of droplets and amounts of liquid Fig. 8.

Tests were also performed by spraying direct onto the animals. The weevils were placed on a nylon net that had been stretched over a Petri dish. The net was comparatively coarse-meshed so as to prevent the animals from moving quickly on the net and so that as little liquid as possible should remain on the bedding.

After spraying light was thrown on the animals from one side so that they crept over onto a piece of cardboard paper and then onto a close-meshed net of tulle. A Petri dish was tipped over them and they were placed under a sodium vapour discharge lamp. The number of mortalities and greatly influenced animals were counted after 20 and 44 hours. As will be seen from the diagram the smallest size of droplet has given the best effect (Fig. 9).

Experiments with DDT against Larvae

Rectangularly cut cabbage leaves were put in jars with water. They were placed obliquely so that the spray hit them at an angle of 45 degrees. After they had dried 5 larvae (larvae from *Pieris rapae* L. and in one experiment larvae of *Pieris brassicae* L.) were placed on the leafage. Counting took



Insecticide l/ha	1,4	1,4	2,0	2,0	2,0
Water l/ha	100	500	100	500	100
Number of tests	2	1	2	2	2

Fig. 10. Laboratory experiments with DDT against the larvae of *Pieris rapae* L. and *P. brassicae* L. *P. rapae* L. to the far right. The diagrams indicate the percentage of dead + greatly influenced animals.
a = untreated, b = MMD 100 μ, c = MMD 270 μ, d = MMD 500 μ.

place as usual after 20 hours. The smallest size of droplet gave the greatest mortality in the tests with larvae Fig. 10.

Field Experiments with Appurtenant Laboratory Experiments

Technical Equipment and Experiment Technics

From the earlier laboratory tests it was clear that a droplet size of 40 μ (medium size of droplet) had given the best result in the experiments made with DDT and parathion whereas the largest size of droplet had shown the best result for the insecticide with systemic action (Systox). For the DDT and parathion preparations it was necessary to test a size of droplet less than 40 μ so as to find out if this gave still better or worse results; if the latter was proved it would mean that there existed a certain optimum size of droplet. As being suitable sizes of droplets 20, 40 and 90 μ were accepted. Here it was therefore necessary to find the nozzles suitable for field experiments and those which could give these sizes of droplets. At these earlier tests a medium size of droplet was originally reckoned on (arithmetical mean).

After laboratory tests with several types of nozzles it was proved that the ordinary Primus nozzle, at a pressure of 15 kg and with disc with

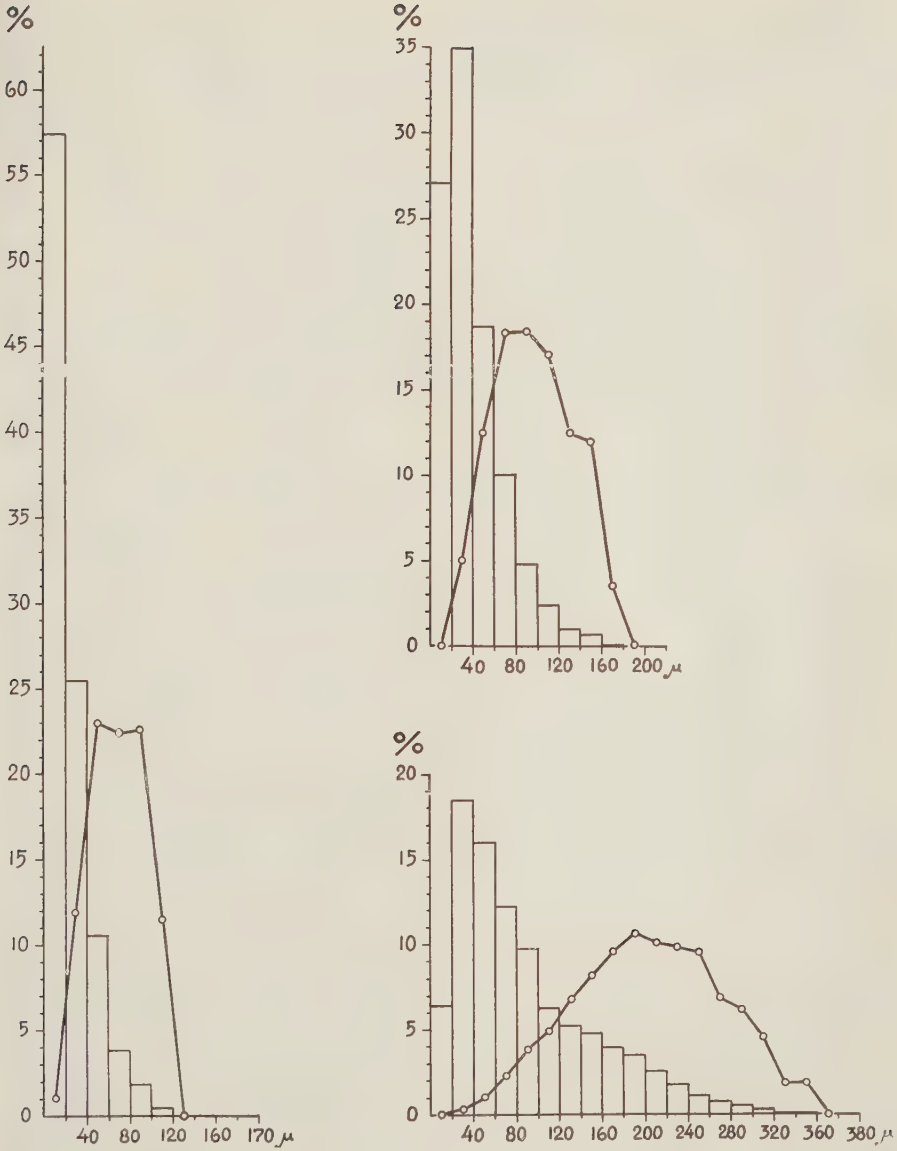


Fig. 11. Distribution of the size of droplets in the nozzles employed in the field experiments. The staple diagrams indicate the percentage in number, the curve the percentage of volume in different classes. The curve below to the right from Hellqvist (1952).

an orifice of 1.1 mm diameter, could give a medium droplet size of 23.8 μ. The nozzle Teejet cone No. 6 was chosen for droplet size 40 μ which, at

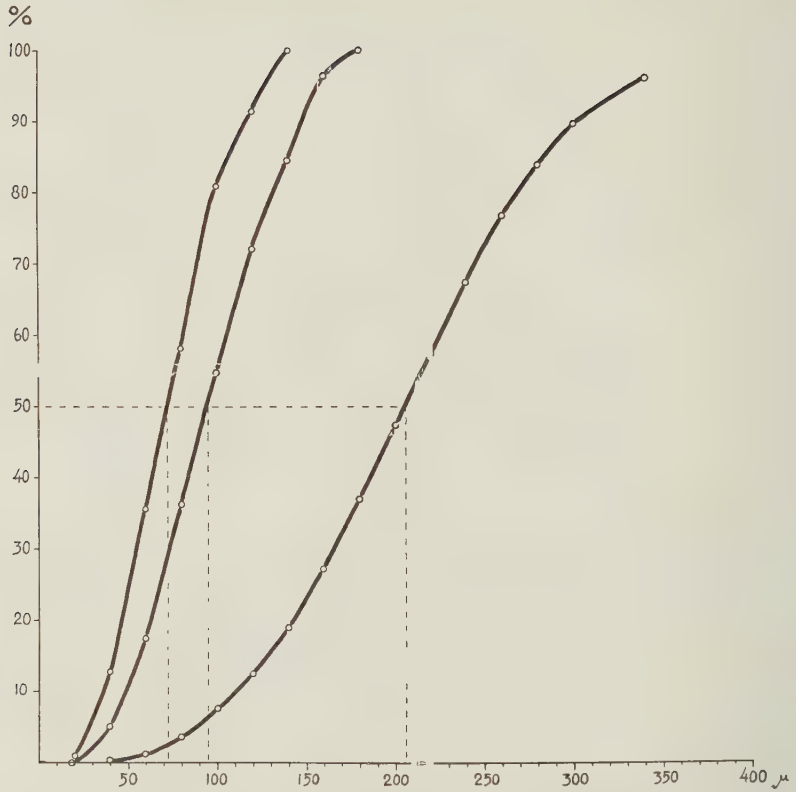


Fig. 12. Curves showing the sprayed volume's distribution of different sizes of droplets in the three nozzles employed in the field experiments. The dotted lines indicate the mass median diameters, MMD, for the three sizes of droplets. See further in the text.

a pressure of 7 kg, gave a medium-sized droplet of 39.9 μ. Teejet 650067 was employed for the largest size of droplet which, according to HELLQVIST's tests (1952) gives a medium-sized droplet of 37.7 μ at a pressure of 5 kg.

The distribution of the sizes of droplets in the different nozzles is made clear in Fig. 11. Scale and classification are the same here as for corresponding diagrams of the sizes of droplets in nozzles employed at earlier laboratory tests. This has been done so as to enable a direct comparison. This size class is not very suitable for the nozzles giving the smallest size of droplet, but it has been used so as to enable comparison. If a smaller size class has been used for this nozzle we find that 26% of the droplets lie between 0.10 μ, 32% between 10 and 20 μ and 14% between 20—30 μ.

As has been mentioned earlier the arithmetical mean of the sizes of droplets characterizes a spray rather badly as far as the size of the droplets

is concerned. MMD (mass median diameter) gives us a far better conception as Brown (1951) shows. Curves of this in the three sizes of droplets used, have been drawn (see Fig. 12) and give MMD 70, 100 and 210 μ. In the following diagrams and tables the sizes of droplets for spraying experiments have been expressed as MMD.

The three nozzles employed are of an approximately similar type; the liquid is pressed out through the nozzle and forms a liquid film, cone-formed in Primus and Teejet cone No. 6, but fan-shaped in the flat-spray nozzle Teejet 650067. These liquid films break into drops of different sizes. If the pressure is greater in a certain nozzle the film becomes thinner and the droplets smaller. Surface tension reducing agents influence the size of the droplet by the same nozzle and pressure. This causes the film to split more easily so that a smaller size of droplet is got on the admixture of such substances.

The size of the droplet is consequently influenced by the type of nozzle, pressure and the characteristics of the solution (for instance surface tension and viscosity).

The Primus nozzle contains a filter, a vortex plate, packing, and outermost a disc with an orifice. Distribution of the liquid in the cone formed, becomes to a great extent dependent on the evenness at the edge of these orifice. The irregularities at the edge of the orifice that is formed when the hole is drilled gives an uneven distribution of the preparation. In discs employed in field experiments the orifices were planed to the size of 1.1 mm diameter after which the discs were tested at Statens Maskinprovningar, Alnarp, in accordance with methods described in a publication from Statens Maskinprovningar (1951). The two other types of nozzles were also tested in a similar manner so as to establish the evenness of the distribution.

The Teejet 650067 nozzle employed consisted of a tap, which was placed in a primus nozzle instead of the disc. A packing was inserted instead of the vortex plate.

In the use of Teejet cone No. 6 the same parts were employed as in the Primus nozzle except that the disc was changed for Teejet cone No. 6.

For the field experiments a sprayer from AB Moteska was employed; in 1955 one which had partly been re-built so as to be better adapted for tests. The sprayer had an Alreco-pump, the manometer was graded 0—25 kg/cm and was pressure-tested at Statens Maskinprovningar, Alnarp. The working width was 8 meters.

The sprayer was further equipped with an Imo water meter which enabled a direct reading of the quantity of liquid sprayed in liters. The water meter was controlled by determining a quantity of sprayed liquid and weighing the sprayer before and after spraying (time of test 5 min.). The

tractor used to drive the sprayer was of Farmall H. make. At a test it gave the following velocities for the different gears:

Gear	I	4.55 km/hour
	II	6.32 »
	III	7.5 »

The amount of liquid sprayed per 100 meters for the different velocities was determined by a driving test. Suitable combinations of the amount of liquid and the sizes of droplets could be reached by varying the nozzles, pressure and rate of movement. In spraying with every other nozzle blind discs were put in and the boom could be raised to about 1.8 meters above the ground in high crops and when only every other nozzle was used.

For each treatment the tractor drove 3—4 times along the length of the field and protective edges consisting of one drive were sprayed on the sides of the experiments and on the sides of the untreated plot. Within each plot 3 (later 5) netting-places were marked. Netting operations were carried out before the spraying and on the 1st, 2nd and 3rd days after. At each netting-place five netting operations were performed across four rows.

For the laboratory tests an arrangement corresponding to that of the field test was made. The same nozzles as in the field experiments were used. These were connected to a pressure chamber with a spraying liquid and the pressure was obtained with compressed air. By means of an electric motor with adjustable velocity a disc could be made to rotate with different numbers of revolutions. A board was fixed to this disc and 60 cm from the centre it was supplied with holes that fitted glass jars of 30 cc. The parts of the plants to be sprayed were placed in such jars and could then be made to pass under the nozzle at a determined velocity. Otherwise the arrangements for these laboratory tests were similar to those made at laboratory experiments earlier mentioned.

Field Experiments with DDT

The first field experiment against rape beetles was begun on the 12th May 1954. The spray solution was 1.5 liters of a DDT compound (Ponocid F25) in 95 liters of water per hectare. The experiment was laid out with one repitition. Two netting operations were performed on each plot. The result of these is given in Fig. 13. Three plants were taken back home from the plots. They were placed with 20 rape beetles on each and counting of the number of dead insects took place 1 and 2 days after the spraying. The result is shown on Table 4.

In this field experiment the original number of beetles is too low for any

Table 4. Percentage of dead + greatly influenced beetles at laboratory experiments with plants from the field experiments on May 12th.

Date	Untreated	MMD 70 μ	MMD 100 μ	MMD 210 μ
13/5	5.6	13.7	29.2	11.1
14/5	7.4	72.6	85.1	49.9

greater differences to appear. In the laboratory test the plants sprayed with the medium size of droplet show the largest number of dead incects.

A second field experiment against rape beetles was laid out on the 17th May 1954. The spray consisted of 1.5 liters of a DDT insecticide (Ponocid) in 95 liters of water. On spraying the weather was fairly calm. The result of the netting operation is reproduced in a diagram (Fig. 13).

No insects seem to have flown in between the first and the second nettings and the effect has been almost 100 per cent. Insects have flown in before the 3rd netting, but the effect seems to have been good even against these, possibly somewhat less in the largest size of droplet. The result of laboratory experiments with plants from the field test is reproduced in Table 5.

Table 5. Percentage of dead + greatly influenced beetles at laboratory experiments with plants from the field experiment on May 17th.

Date	Untreated	MMD 70 μ	MMD 100 μ	MMD 210 μ
19/5	1.7	48.9	50.6	53.7
20/5	1.7	50.6	69.6	65.1

Another experiment with DDT against rape beetles was laid out on the 5th May 1954. The amount of insecticide per hectare was the same (1.5 liters) as in earlier tests, the amount of water 270 l/ha. The wind was rather violent and blew across the experimental field diagonally. As will be seen from a diagram (Fig. 13) the increase in the number of animals in the untreated area has been rather great between the netting before the spraying and the first netting after. The number of animals has also increased in the largest size of droplet; the effect has obviously not been sufficient to kill any great number of animals whereas with the smallest size of droplet the number of animals is the same before and after spraying. Only the medium size of droplet shows a smaller number of animals the day after spraying. At the third netting operation the differences have been smoothed out to a great extent. (The figures show that the animals have come in with the wind from one side.) Laboratory test with plants from the field were performed, too. The result is given in Table 6.

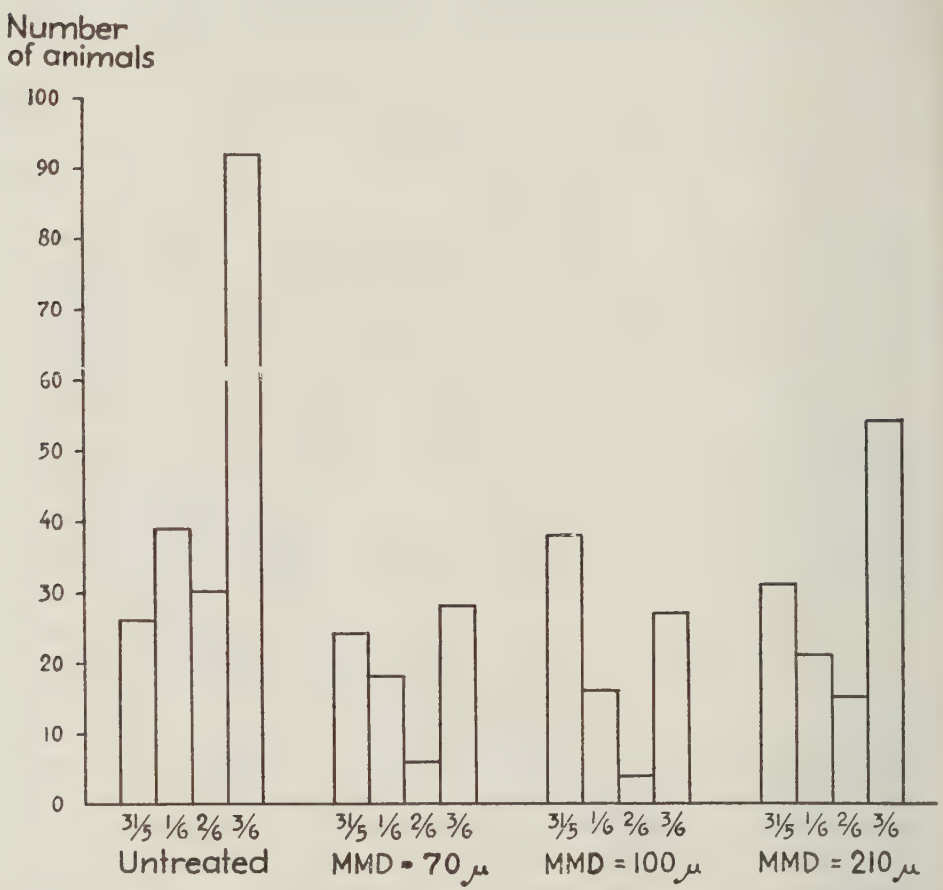


Fig. 14. Field experiments with DDT against rape beetle (*Meligethes aeneus* F.). The staples indicate the number of dead animals as an average of 5 netting operations. See further in the text.

Table 6. Percentage of dead + greatly influenced beetles at laboratory experiments with plants from the field experiment on May 18th.

Date	Untreated	MMD 70 µ	MMD 100 µ	MMD 210 µ
19/5	8.3	46.7	43.3	46.7
20/5	21.7	91.7	93.3	93.3

A field experiment against rape beetles was laid out on the 27th May 1955. The amount of insecticide was 1.5 liters of a DDT compound per hectare in 95 liters of water per hectare. The wind was very mild on spraying

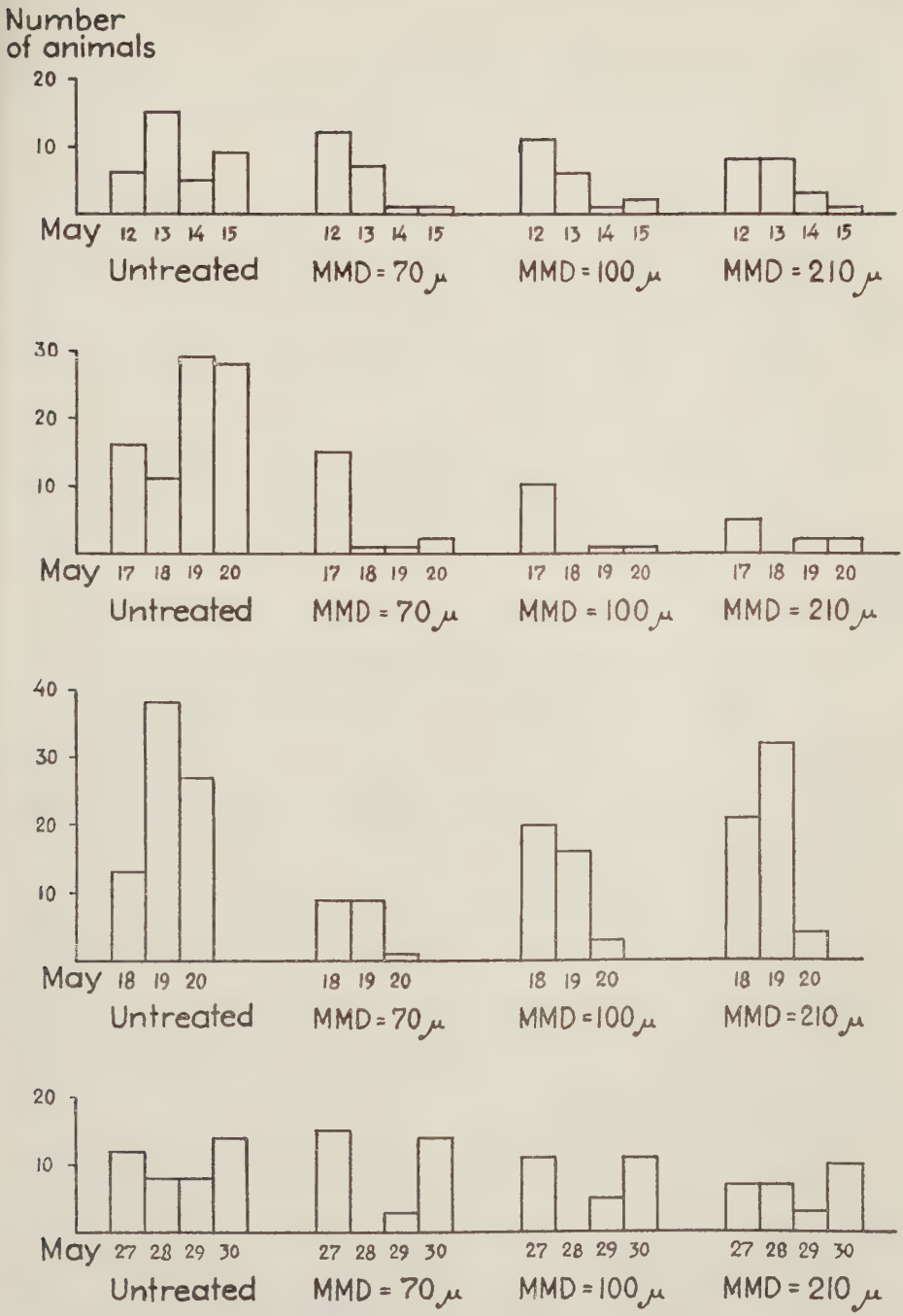
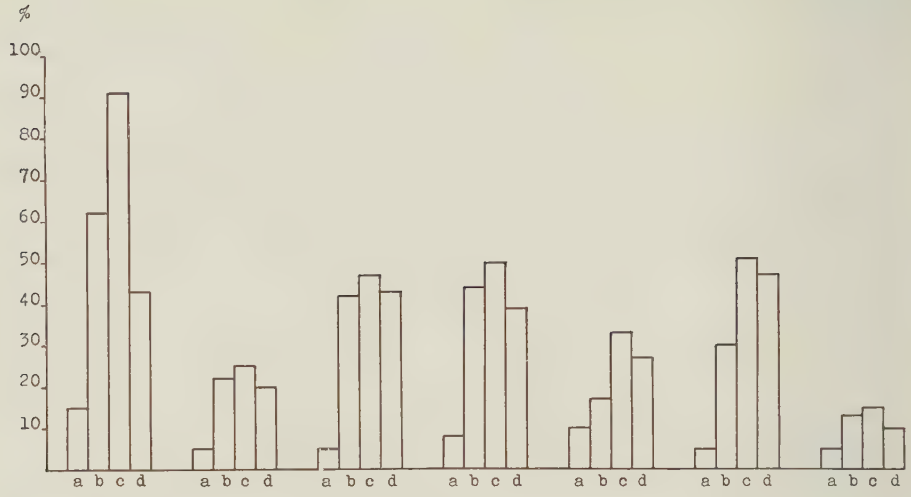


Fig. 13. Field experiments with DDT against rape beetle (*Meligethes aeneus* F.). Each staple indicates the number of animals as an average of 3—5 netting operations.



nsecticide l/ha	1,5	2,0	2,5	2,0	1,5	2,5	2,0
Water l/ha	95	125	125	250	470	600	600
Number of tests	1	1	1	5	2	1	1

Fig. 15. Laboratory experiments with DDT against rape beetle *(Meligethes aeneus* F.). The diagrams indicate the percentage of dead + gratly influenced animals. a = untreated, b = MMD 100 μ, c = MMD 270 μ, d = MMD 500 μ.

and the temperature 13.5°C. The result of the netting operations (5 netting-places per plot have been used here) is given in a diagram (Fig. 13). The two small sizes of droplets seem to have given the best result.

On the 31st May 1955 another field experiment against rape beeties was laid out and the number of beetles was considerably greater here. The amount of liquid and the amount of insecticide were the same as in previous experiments. The wind was insignificant and on spraying (which happened in the evening) the temperature was 12.5°C. As will be seen from the result of the netting operation (Fig. 14) a great number of insects have flown in between the last netting and the one before. The largest size of droplet has given a worse result than the two smaller ones, which is proved by statistics (probability $0.05<p<0.01$).

Besides field experiments, laboratory experiments have also been performed with the same nozzles as in the field tests and the same equipment as earlier mentioned. These have been placed together in a diagram (Fig. 15). The medium size of droplet has given the best result for all amounts of liquids and concentrations.

By the laboratory experiments and field experiments it must be considered clear that an optimum distribution of the size of droplet exists with a MMD

of somewhere between 70 and 200 μ (where 200 μ is too large and 70 μ probably too low) which is well in accordance with earlier reported foreign experiences of an optimum MMD of 130 μ and an optimum distribution of the droplets between 80 and 150 μ.

Field Experiments with Parathion

In 1954 only one experiment was laid out against rape weevils. The number of animals was so small (Fig. 16) that nothing can be concluded from the test. Nor is there any intimation of the larger size of droplet having given a poorer effect. In laboratory tests (Table 7) with plants from experiments the medium size of droplet gave the greatest mortality.

Table 7. Percentage of dead + influenced weevils in laboratory experiments with plants from field experiments laid out on May 29th.

Date	Untreated	MMD 70 μ	MMD 100 μ	MMD 210 μ
30/5	3.3	5	10	3.3
31/5	3.3	8.3	30	6.7
1/6	3.3	21.7	38.3	11.7

In 1955, too, the number of rape weevils was very few owing to the exceptional state of the weather. An experiment was laid out on the 3rd June. The insecticide was Ewotox forte (45% active substance) 2/3 of a liter and water 95 l/ha. The rape blossomed and was very sound. On spraying the temperature was approx. 13°C and the wind insignificant (the experiment was laid out in the evening). The effect of the spraying was very weak. For rape weevils the effect between the first and second netting operations rather seems to indicate a somewhat better action of the largest size of droplet. The difference for rape beetles treated in earlier tests show the effect to be greatest for the medium size of droplet. At a test laid out on the 6th June the netting could only be done for two days on account of rain. The amount of liquid was here 270 l/ha. Spraying with the smallest size of droplet does not appear to have had any effect on the rape weevils here; the two larger sizes of droplets have had greater effect whereas for rape beetles the medium size of droplet seems to have given the best result. Still, the number of animals is far too small to draw any conclusions. The results of these experiments will be seen in Fig. 16.

Consequently the results of the experiments in fields with parathion are difficult to interpret and are hardly in keeping with the laboratory tests. A laboratory test with parathion was carried out with the same nozzles as in the field experiments. This gave the greatest mortality for the medium

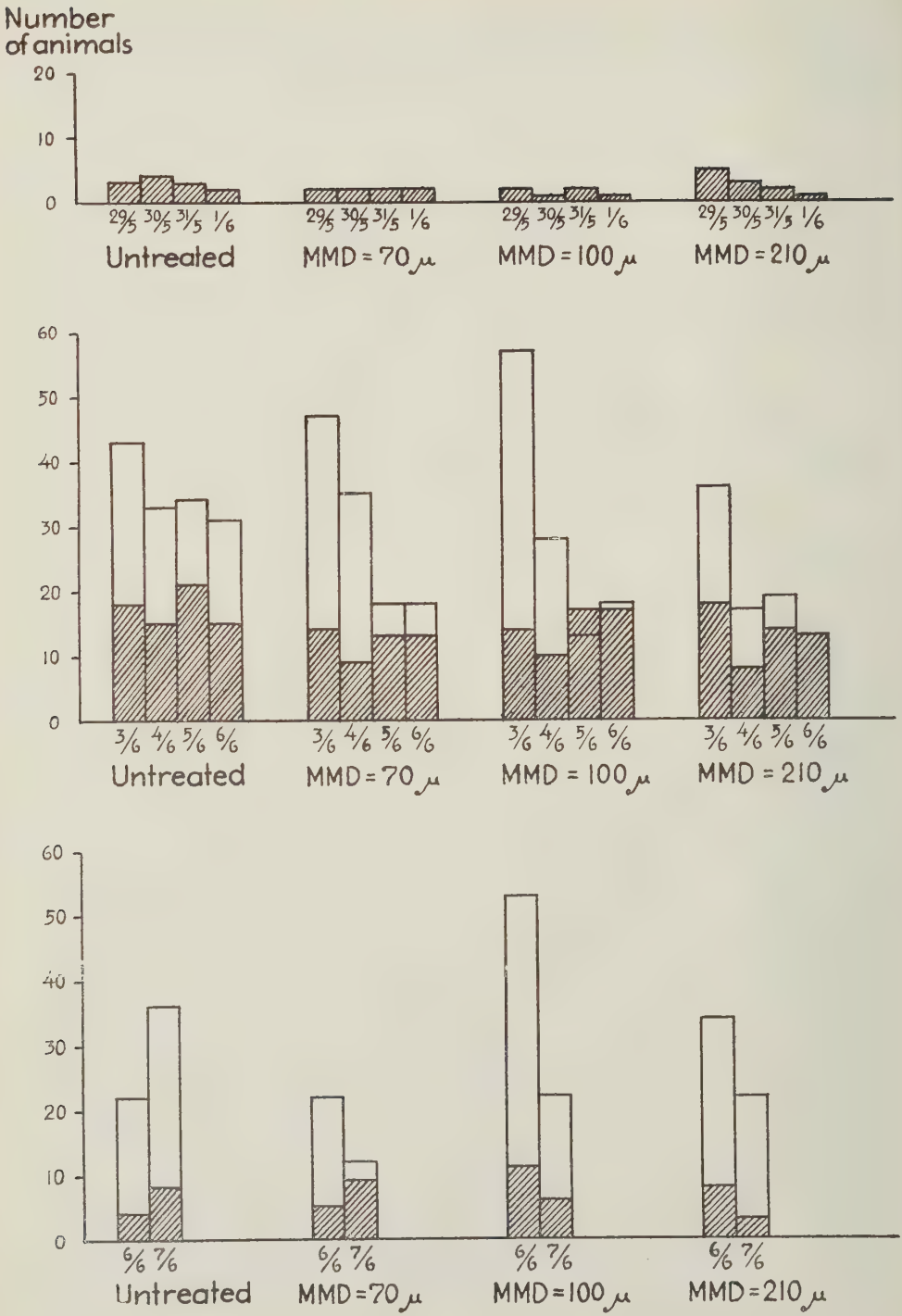


Fig. 16. Field experiments with parathion against rape weevil. *(Ceutorrhynchus* ssp) and rape beetle *(Meligethes aeneus* F.). The top diagram indicate the number of animals as the average of 3 netting operations; the two bottom ones the average of 5 netting operations. The filled part of the staple rape weevils, the whole staple rape beetles.

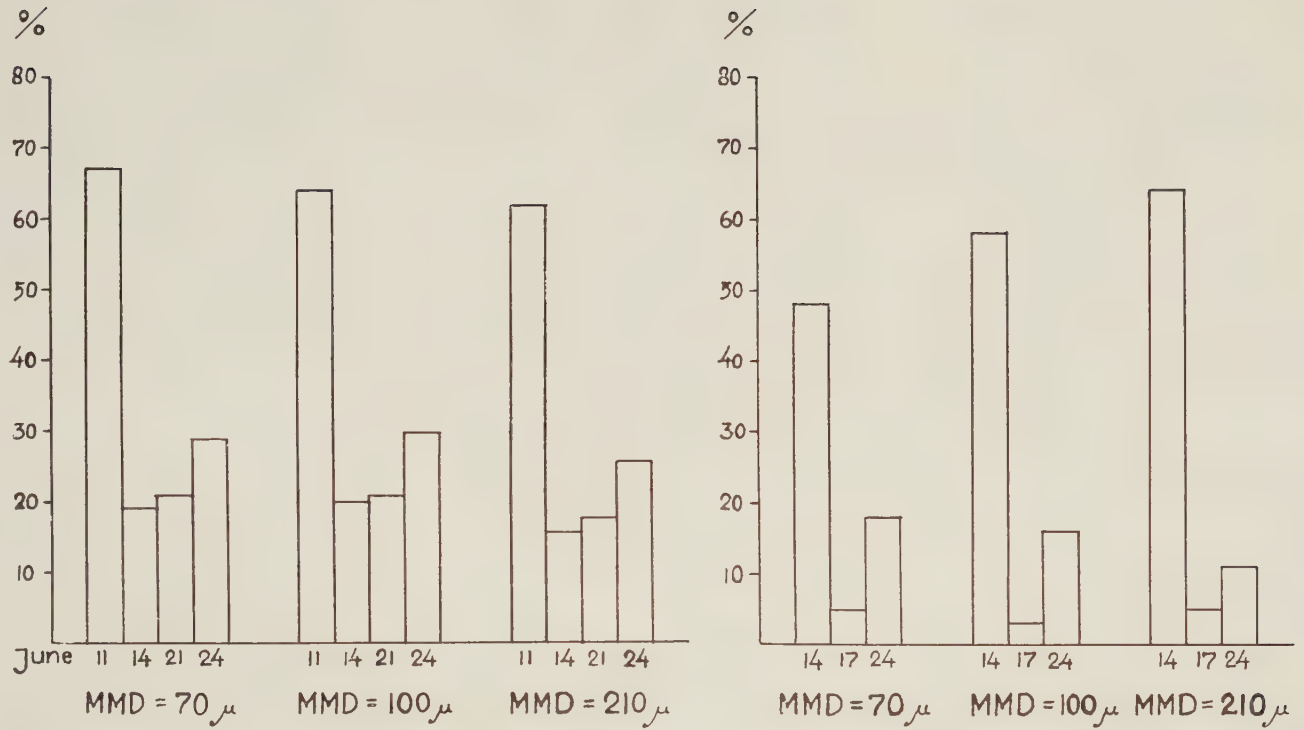


Fig. 17. Field experiments with Systox against aphids in sugar-bets. The left diagram 0.3 l of Systox in 270 l/ha; the right diagram 0.3 l of Systox in 470 l/ha. The staples indicate the percentage of plants affected.

size of droplet, but as there is only this experiment to judge by, no conclusions can be drawn from it.

Laboratory experiments with malathion and diazinon compounds have been performed, too. The malathion insecticide gave the best effect for the medium size of droplet (independent of the quantity of liquid) whereas the diazinon compound gave the best effect for the medium-sized drop for 100 l/ha and the best effect for the smallest ones with larger quantities of liquid. The animals experimented on were larvae of the turnip sawfly (*Athalia colibri* Christ.) and curled kale was the plant used. Otherwise the experimental arrangements were the same as at earlier experiments. The caterpillars, however, were very troublesome to work with ; several of them changed their skins (the last change of skin to grey) during the experiment and then did not eat, but just crawled about.

Field Experiments with Systox

An organic phosphate with systemic action (Systox) was tried against beet aphids. From 100 plants the number of those affected was counted at three places in each plot. In an experiment on seed beets on the 11th June, 0.3 liter of Systox was used in 270 l/ha. The result of this test is seen in Fig. 17. The two smaller sizes of droplets are more or less alike whereas the largest has given a somewhat better result. At an experiment on the 14th June with the same amount of active substance but 470 liters of liquid per hectare and also performed on seed beets, a similar result was obtained (see Fig. 17).

An experiment on beets with 0.3 liter of Systox in 270 l/ha (Fig. 18) gave a very low mortality, but it also gave a better result for the larger sizes of droplets. Consequently the results agree with the previous laboratory experiments.

Discussion on Experiment Methodics

The field experiments have given many valuable experiences as to suitable methodics in spraying experiments with insecticides in fields, but they have also shown the difficulties in realizing such. The mere problem of getting a suitable-sized field about 200 300 meters long and at least 100 wide is very difficult. Furthermore the same field should slope as little as possible, so that one can keep pace with the tractor. Moreover it should have a uniform crop. At experiments on rape beetles and rape weevils the frequency of insects should of course be fairly great and regular which it hardly is if the field is large. Only one experiment with no repitition with two drives for each treatment as in the previous one, gives with the length abovementioned an area of 2 hectares. If the experiments are to be laid several times, the experiment consequently becomes very great. In order to get a

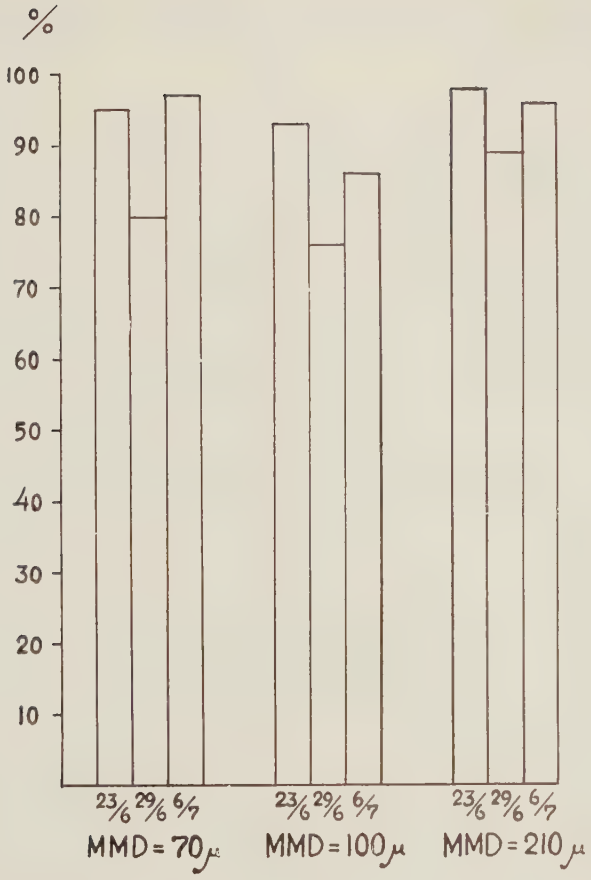


Fig. 18. Field experiments with Systox against aphids in sugar-beets. 0.3 l of Systox in 270 l/ha. The staples indicate the percentage of plants affected.

result which can be statistically worked out quite a large number of netting operations will be necessary (the 3 originally carried out for each experimental plot are too few). The distribution between the values is, as a rule, great. Furthermore careful observations of the wind, temperature and local conditions will be necessary in order to be able to interpret the experiments correctly. As to tests with Systox for instance a reading of the size of evaporation should also take place.

As medium-sized droplets were originally reckoned on in these investigations the experiments have unfortunately been performed with droplets sizes of a MMD which might otherwise have been more suitable. The two smaller sizes of droplets as is seen by the curves (Fig. 12) lie rather near to each other whereas the distance to the largest size of droplet is greater.

If possible sprays with as narrow a »droplet size spectrum» as possibles should be employed in experiments (the largest size of droplet has a very wide »spectrum»).

Distribution of the Spray, Drift and Evaporation

As the effect of the larger sizes of dropled proved best both at laboratory and field experiments with Systox certain test were carried out with this insecticide in order to try to establish the reason for this.

As evaporation of the insecticide could be thought to influence absorption, the plants were sprayed and dried partly in an exsiccator partly in a moist chamber after which the insects (10 beet aphids) were placed on the plants. Reading took place after 20 hours. The results are given in Table 8. In drying in an exsiccator MMD 210 μ has given the highest mortality ; in drying in a moist chamber MMD 100 μ. Adapted statistically it is proved that these differences in the sizes of the droplets is significant for drying in an exsiccator $0.01<p<0.001$, and for drying in a moist chamber $p>0.001$.

Evaporation has obviously influenced the mortality in different sizes of droplets. However, it is strange that the largest size of droplet should have given such a low mean for drying in a moist chamber.

In order to establish how the droplets distribute themselves in vegetation a field experiment was performed with a solution of common salt sprayed on rape where samples of leaves were taken from a distance of about 30, 50 and 70 cm. from tre nozzles. The salt solution contained 184 g of NaCl per liter and the amounts sprayed were equivalent to 250 and 600 l/ha. At different heights in the crop samples of leaves were taken. From these 20

Table 8. Plants sprayed with Systox 0.5 liter in 250 liters per hectare and dried in an exsiccator and a moist chamber. Percentage of dead aphids at the different treatments.

Dried in an exsiccator				Dried in a moist chamber			
Date	MMD 70 μ	MMD 100 μ	MMD 210 μ	Date	MMD 70 μ	MMD 100 μ	MMD 210 μ
17/6	63.3	86.7	96.7	23/6	81.7	90.0	83.3
22/6	80.0	83.3	96.7	28/6	56.7	96.7	70.0
23/6	53.3	63.3	90.0	29/6	36.7	42.2	26.7
7/7	10.0	20.0	26.7	2/7	3.3	20.0	10.0
8/7	18.5	48.1	62.6	5/7	13.3	13.3	6.7
				6/7	31.9	73.3	71.3
				7/7	3.3	26.7	3.3
				9/7	40.0	66.1	44.8
Average	45.0	60.3	74.5	Average	33.4	53.5	39.5

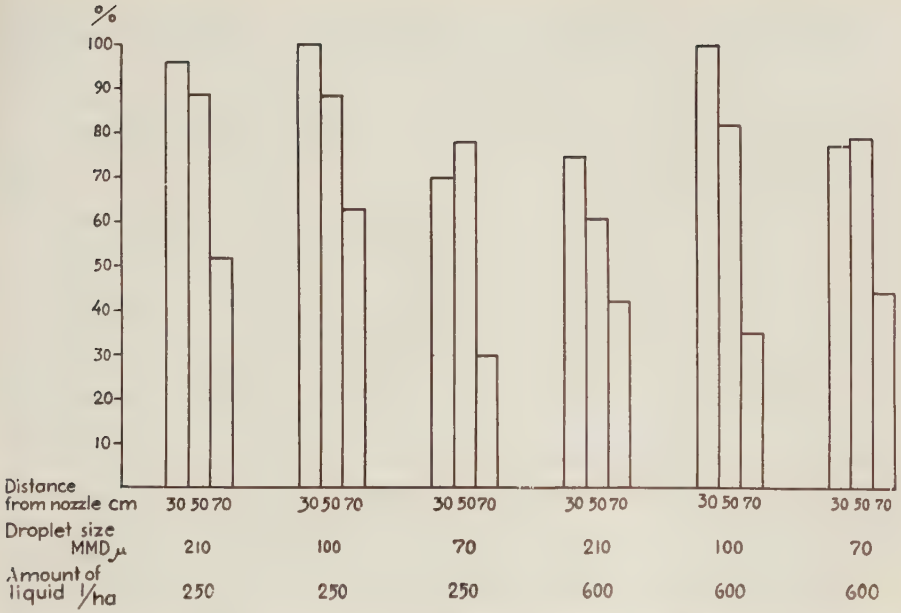


Fig. 19. Distribution of a solution of NaCl sprayed on a crop of rape at different distances from the nozzles and with different sizes of droplets. With 250 l/ha expressed in % of the amount at 30 cm and the size of droplets 100 μ MMD. With 600 l/ha expressed in % of the amount at 30 cm and the size of droplet 100 μ MMD in this amount of liquid.

circular plates having a total surface af 12.72 cm^2 were punched with a cork drill. The salt was then dissolved in 10 cm^3 distilled water and the liquid titrated with 0.01-n $AgNO_3$-solution towards the indicator K_2CrO_4. Three parallels were taken at each height of the crop. Fig. 19 shows the result. The percentage of NaCl has been calculated in relation to the amount of residue of NaCl for the medium size of droplet and the distance of 30 cm. If we sum up the amounts of NaCl recovered at different distances from the nozzle we come to for the different sizes of droplets 210 μ 3.74 mg, 100 μ 3.97 mg and 70 μ 2.81 mg for 250 l/ha ; for 600 l/ha the corresponding figures are 4.44 mg, 5.44 mg and 5.03 mg.

Irrespective of the amount of liquid, the medium size of droplet has consequently given the greatest amount of residue which of course explains the better action of this size of droplet at experiments with DDT.

In table 9 the amounts of residue are represented in a percentage of the calculated amounts. That such a small part has been recovered is of course due to the fact that the surface of the leaves per hectare on which the spray distributes itself has an area of many hectares; the leaves are not placed horisontally but cover each other and so on. It is of intrest to note that 600

Table 9. Distribution of a solution of NaCl sprayed at differents heights in a crop of rape. The amount of residue in percentage of that sprayed.

Amount of liquid, l/ha	Droplet size MMD μ	Distance from nozzle, cm	Amount of NaCl-solution, $mm^3$12.72 cm^2	Amount of residue in % of calculated
250	210	30	8.26	25.97
	210	50	7.61	23.93
	210	70	4.46	14.03
	100	30	8.59	27.01
	100	50	7.61	23.93
	100	70	5.38	16.92
	70	30	6.03	18.96
	70	50	6.68	21.01
	70	70	2.55	8.02
600	210	30	10.16	13.31
	210	50	8.26	10.82
	210	70	5.71	7.48
	100	30	13.61	17.87
	100	50	11.14	14.60
	100	70	4.78	6.26
	70	30	10.49	13.74
	70	50	10.82	14.18
	70	70	6.03	7.90

l/ha give a considerably smaller amount of residue when counted at a percentage. This must be due to the increase in the run-off in larger amounts of liquid.

If we look at the diagram (Fig. 19) and compare the largest and medium sizes of droplets in the two amounts of liquid we find (for 30 and 50 cm) that the amount of NaCl at 210 μ has decreased in relation to 100 μ. The simplest explanation of this is that the run-off in 210 μ is greater from the beginning and that it has increased more in 210 μ. The largest droplets here (which are up to 500 μ) do not get deposited on the leafage and although they are rather few in number they play an important part as regards volume and the amount of substance.

If we compare 100 μ with 70 μ in the amounts of liquid we find that the amount of NaCl in the size of droplet 70 μ is considerably lower. As is seen from the earlier representation this can be explained by saying that it is due to the fact that a smaller number of small droplets are deposited because of a smaller momentum (Yeoman and Rogers 1953), greater evaporation (a drop of 10 μ evaporates according to Shepard (1951) in 0.05 sec. in calm air) and greater drift.

The droplet size 70 μ does not show a similar decrease in the amount of NaCl as 210 μ in relation to 100 μ when the amount of liquid increases from 250 liters to 600 liters per hectare. The run-off has obviously increased about the same for these two sizes of droplets.

From a practical viewpoint the most interesting thing to note is that if

the concentration is the same a larger spray volume certainly gives an increased amount of substance on the leafage, but that considerably more substance is lost.

The distribution of the droplets was also studied by adding fluorescent material to the spray according to a method worked out by SHARP (1955). A dye, Primulin AS, in an amount of 0.11 per cent of the liquid sprayed, was added to the spray. SHARP has used a somwhat different type of Primulin. Instead of Celacol, the cellulose preparation employed by SHARP, a swedish cellulose compound, Cellufix (a 1% solution) was used and besides that Shellestol was employed as a surface tension reducing agent. If this admixture is sprayed the Primulin fluorescens after drying together with the cellulose with a bright yellow-green fluorescence in ultraviolet light. The spraying was performed with the afore-mentioned equipment for laboratory experiments and with the nozzles employed at the field tests. From 8 rape leaves sprayed pieces of 2×2.5 cm were cut out and pasted onto pieces of cardboard paper and photographed in ultraviolet light (the lamp employed was of the type which is used in seed control and it also gave a blue light). On taking the photograph a yellow-green filter was employed and an Isopan F film. On account of the film being comparatively sensitive the time of exposure could be held at 2—3 min.

Fig. 20 shows pictures of the three sizes of droplets sprayed with an amount of liquid of about 100 l/ha. The largest fluorescent points here give the largest size of droplet and the smallest size of droplet (in the latter case the larger points lie more sparsely). The medium size of droplet gives the largest number of spots. The number of droplets per square centimeter was counted on the film by projecting it. For the largest size of droplet it was 50 spots per square centimeter ; for the medium 89 spots per square centimeter and for the smallest size 56 spots per square centimeter. If the size of the spots was measured we got 91% above 1/2 mm. for the largest size of droplet, 2 % above 1/2 mm for the medium size, and 44 % above 1/2 mm for the smallest. Consequently the medium size of droplet gave the largest number of visible spots per square centimeter and the smallest spots. That the smallest size of droplet gave few and larger spots can be explained as partly being due to evaporation and drift and maybe partly to the droplets, which have lain very close to each other, having floated together and formed larger units (small droplets of course form a film over a surface more quickly). Furthermore through the comparatively small momentum in the small droplets they may not have arrived or have been taken up by the larger droplets having a greater momentum i spraying (BROWN 1951).

In spraying with larger quantities of liquid of about 250 l/ha the photos show that we get a film more quickly and thereby a quicker run-off from

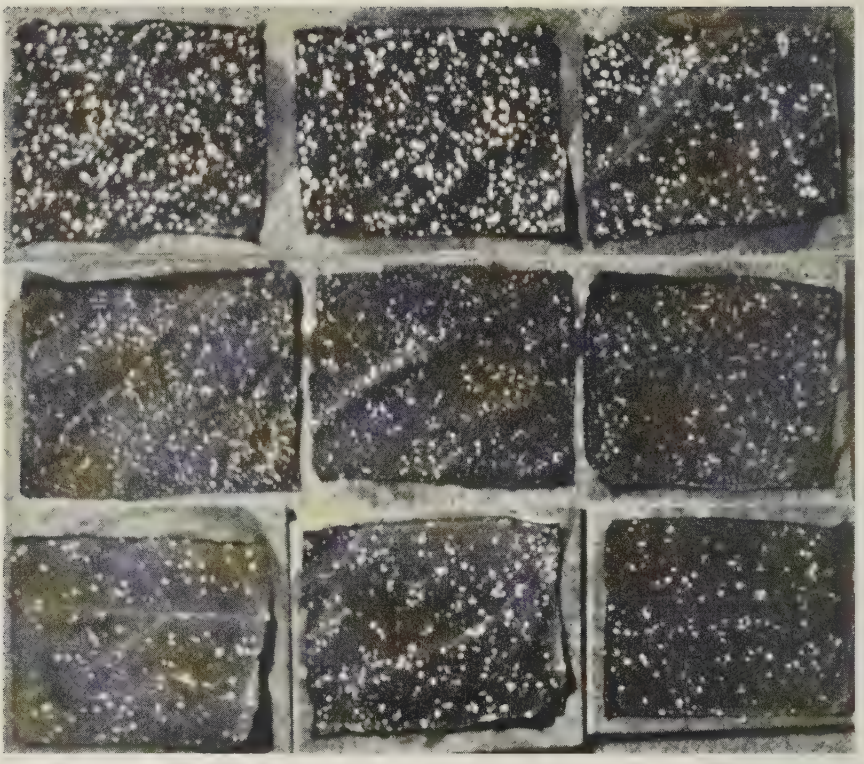


Fig. 20. Distribution of the spraying liquid in different sizes of droplets. Amount of liquid approx. 100 l/ha. The largest size of droplet (MMD = 210 μ) at the top; the medium (MMD = 100 μ) in the middle and the smallest (MMD = 70 μ) at the bottom. A fluorescent substance added to the spraying liquid and a photograph in ultravilolet light. Enlargement × 1.5. See further in the text.

the largest and smallest sizes of droplets. See Fig. 21. These results are well in accordance with what has been stated at the spraying experiment on rape with a solution of NaCl.

In order to get an idea of the ability of the droplets to get round obstacles i.e. to penetrate a crop where the leafage covers each other, an experiment was performed by spraying leaves over which a round sheet of cardboard paper was fixed at a distance of 1 cm above the leaf. The diameter of the sheet was 2.5 cm. The place of the sheet was marked after spraying and drying the leaf with a brush dipped in fluorescent liquid. See Fig. 22. The photos show that practically speaking a total »drop shadow» is got for the largest size of droplet ; the »spray shadow» is also powerful for the smallest size of droplet whereas it is almost indiscernible for the medium size of droplet. Consequently in a crop if leafage or parts of plants cover each

Fig. 21. Distribution of the spraying liquid in different sizes of droplets. A fluorescent substance added and a photograph in ultraviolet light. The two leaves MMD 210 μ, the two middle ones MMD 100 μ and the two right ones MDD 70 μ. The amount of liquid approx. 270 l/ha. See further in the text. Natural size.

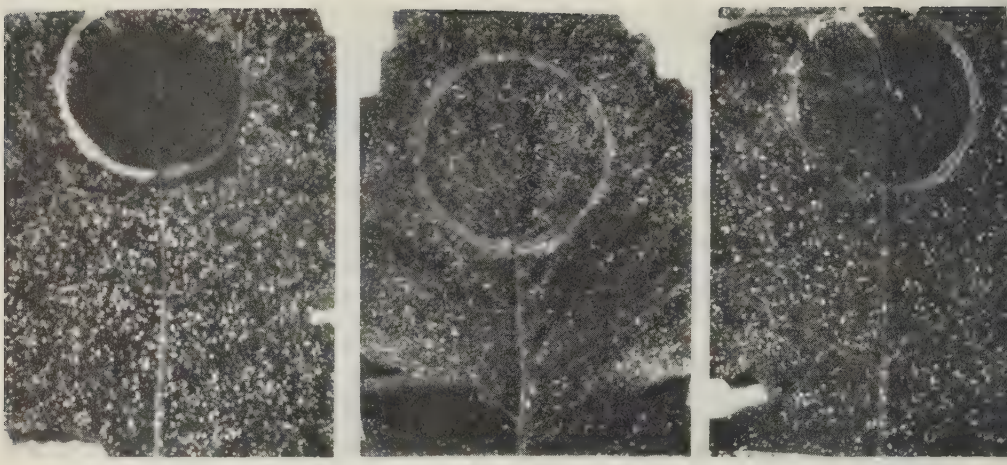


Fig. 22. Distribution of the different sizes of droplets on a partly covered leaf. From left tog ri the sizes of the droplets are 210 μ, 100 μ and 70 μ MMD. See further in the text. Natural siz

other the medium size of droplet has the greatest power of being distributed evenly, to »penetrate» the crop. This result is also well in accordance with the results of the NaCl spray on rape with a corresponding amount of liquid.

Consequently the better action of the medium size of droplet, MMD 100 μ can be considered due to the better distribution of the insecticide in a horizontal and vertical line in a crop and the decreased run-off which is a result of it.

Fluorescent liquid was also tested in order to study wind drift. 10 cm^2 large sheets of black cardboard were laid out in a fan-shaped pattern with a distance of 50 cm between the sheet in one experiment and at a distance of 5 meters from the place of spraying ; in the following experiment the distance between the sheet was 1 meter and the length 10 meter. They were then sprayed at different times with the nozzles so that they gave the same amount of liquid. The wind was measured during the spray. The wind forces at the tests remained between 2.1 and 3.5 metres a second. However, counting the number of fluorescent points per square centimeter proved very troublesome ; it had to be done in ultraviolet light and it was impossible to take photos. The boundary between visible and scarcely visible droplets was very wavering. The plate nearest the nozzles could not be counted either, as here the droplets had floated together. From the tests, however, it could be established that in wind forces of 2.1—2.9 m/sec wind drift gave fully visible fluorescent points at a distance of 5 metres both straight in the direction of the wind and also obliquely along with the direction of the wind. The medium size of droplet gave the greatest drift which could be established both purely ocularly and by counting the number of

droplets. It is quite natural for such to be the case. The drift we have to deal with here could in our case be called a »useful» drift i.e. these droplets are so large that they sediment and are deposited. The droplets in the smallest size of droplet can to a greater extent be carried by the wind and sediment less. The drift of the largest droplets is of course not so great as they sediment earlier.

Bits of herbarium paper saturated with kitonechtgrün were also tested for simple wind drift experiments. This, however, proved itself an inapplicable method on account of its insignificant sensitiveness to small droplets and the impossibility of counting the droplets.

The best thing to do is to lay out ordinary object glasses, spray with a fluorescent substance and then photograph the glasses in ultraviolet light in a microscope. To do this quite an expensive equipment is taken for granted as is also the case if one wishes to determine the amount of substance fluormetrically.

At wind drift tests evaporation was also measured with an atmometer made from TANSLEY's (1946) description and originally constructed by Dr W. O. James, Oxford. It consists of an upper part of porous china where the water evaporates and the velocity is measured by determining the time that a bubble of air in a tube requires to go up the scale when the water is sucked up to upper part from a container. This instrument is simple and very well adapted for determining evaporation at wind drift and spraying experiments. Particularly at spraying tests with insecticides with a systemic action it will be necessary to measure the evaporation, since this obviously influences the effect.

Summary

1. Theoretical discussions speak in favour of certain optimum size of droplet existing in spraying with a liquid that is to be deposited on vegetation.

a) very small droplets are very liable to drift. They follow to a great extent the stream of air past the insects and vegetation in spraying. They evaporate very quickly, sediment slowly and have to have great initial velocity in order to be deposited on vegetation.

b) very large droplets distribute themselves unevenly in vegetation and instead of being deposited they at once run off.

2. The most applicable single figure for indicating the size of droplet in spraying is the mass median diameter, MMD; one half of the volume in spraying has a size of droplet that is less than MMD, the other half of the volume has a droplet size that is larger.

3. In judging the spraying equipment from the droplet size viewpoint it is

important when testing sprays that the following things should be established:

a) the MMD and within what part of the »droplet size spectrum» the greatest part of the sprayed volume is to be found. This can be done by constructing curves similar to those in Figures 3 and 12.

b) how the »droplet size spectrum» and the MMD can be varied by means of different nozzles, pressure and other equipment.

c) the amount of active substance that is deposited on vegetation in different droplet spectra and MMD.

4. On comparison between different insecticides consideration should be taken to their character of emulsions of different kinds. If the insecticide is an emulsion it will be influenced not only by the active substance but by the nature of the oil, emulsifier, wetting agent, electrolytes present and the pH value of the liquid.

5. At spraying experiments in laboratories with three different sizes of droplets MMD 100 μ, 280 μ and 500 μ, the following results have been obtained:

a) in experiments with DDT against rape beetles the smallest size of droplet has given the greatest effect.

b) in experiments with DDT against corn weevils by spraying on wooden plates no difference has appeared in the action between different sizes of droplets. In spraying onto the animals direct the smallest size of droplet has given the best effect.

c) in experiments with DDT against the larvae of *Pieris rapae* L. and *P. brassicae* L. the smallest size of droplet has given the best result.

d) in experiments with parathion against rape weevils the smallest size of droplet has had the greatest effect.

e) in experiments with nicotine against aphids no differences have appeared between the different sizes of droplets.

f) in experiments with Systox against aphids the largest size of droplet has given the best result.

g) different amounts of liquid and amounts of insecticide have been tested, but the amounts of liquid do not seem to have been of any significance worth mentioning. The amount of active substance sprayed has been decisive.

6. In field experiments with the droplet sizes MMD 70 μ, 100 μ and 210 μ the following results have been obtained:

a) in experiments with DDT against rape beetle the best result has been obtained with the two smaller sizes of droplets.

b) field experiments with parathion have not given any result as to the best size of droplet.

c) field experiments with Systox against beet aphids have given the best result for the largest size of droplet.

7. The author also discusses the methodics in field experiments and points out that at further necessary field experiments especially with parathion and insecticides with a systemic action evaporation should be measured by means of a simple atmometer which has been tested by the author with a good result. In addition there should be the usual careful meteorological and ecological observations.

8. Experiments with a solution of NaCl sprayed on rape with the same size of droplet as in field experiments show that the largest amount of salt solution was recovered in the droplet size MMD 100 μ. Consequently the better action of DDT in this size of droplet can be considered due to the fact that the amount of active substance deposited on vegetation is greatest in this size of droplet. This can be explained in the following way:

a) the experiments adding a fluorescent substance to the spray indicate that the droplet size 100 μ MMD is more evenly distributed in a vertical and horizontal line.

b) the experiments adding a fluorescent substance also show that the droplets do not flow together so easily in this size of droplet and consequently that the run-off should be less ; this is also indicated by the NaCl experiment.

9. That the best result in spraying with Systox has been obtained with the largest size of droplet 210 μ MMD, can be explained by the great volatility of this substance compared with that of other insecticides. Experiments by drying plants in an exsiccator and in a moist chamber show that the differences in favour of the largest size of droplet are smoothed out in drying in moist air (the droplet size 100 μ has here given the largest number of dead insects).

10. In order to study the distribution and wind drift of the insecticides the author has used a fluorescent substance as an admixture to the spraying liquid. This constitutes a valuable means of help, as the distribution of the droplets can be studied direct or photographed in ultraviolet light.

Droppstorlekens betydelse vid besprutning med insecticider

Sammanfattning

1. Teoretiska överläggningar talar för att en viss optimal droppstorlek existerar vid spruining med en vätska som skall fästa på vegetationen.
   a) mycket små droppar är mycket utsatta för avdrift, de följer i stor utsträckning med luftströmmen förbi insekter och vegetation vid sprutningen, de avdunstar mycket snabbt, sedimenterar långsamt och måste ha stor utgångshastighet för att fastna på vegetationen.
   b) mycket stora droppar fördelar sig ojämnt på vegetationen och de fastnar inte utan avrinner omedelbart.
2. Den mest användbara siffran för angivande av droppstorleken vid besprutning är massmediandiametern, MMD, ena hälften av volymen vid besprutningen har en droppstorlek som är mindre än MMD, andra hälften av volymen en droppstorlek som är större.
3. För bedömningen av besprutningsutrustningen ur droppstorlekssynpunkt vore det av vikt om vid provning av sprutor följande kunde fastställas:
   a) MMD och inom vilken del av droppstorleksspektrum största delen av den utsprutade volymen befinner sig. Detta kan ske genom konstruktion av kurvor liknande dem i fig. 3 och 12.
   b) hur droppstorleksspektrum och MMD kan varieras med hjälp av olika munstycken, tryck och övrig utrustning.
   c) mängden verksam substans som fastnar på vegetationen vid olika droppspektra och MMD.
4. Vid jämförelse mellan olika bekämpningsmedel bör hänsyn tas till deras karaktär av emulsioner av olika slag. Om bekämpningsmedlet är en emulsion kommer det att påverkas utom av den verksamma substansen av oljans natur, emulgator, vätningsmedel, närvarande elektrolyter och vätskans pH-värde.
5. Vid besprutningsförsök i laboratorium med tre olika droppstorlekar, MMD 100 μ, 280 μ och 500 μ, har följande resultat erhållits:
   a) i försöken med DDT-preparat mot rapsbaggar har den minsta droppstorleken givit störst effekt.
   b) i försöken med DDT-preparat mot kornvivlar med sprutning på träplattor har ingen skillnad i verkan mellan olika droppstorlekar

framkommit; vid sprutning direkt på djuren har den minsta droppstorleken givit bäst effekt.

c) i försöken med DDT-preparat mot rovfjärils- och kålfjärilslarver har den minsta storleken givit bäst resultat.

d) i försöken med parationpreparat mot rapsvivlar har den minsta droppstorleken haft störst effekt.

e) i försöken med nikotinpreparat mot bladlöss har inga skillnader framkommit mellan olika droppstorlekar.

f) i försöken med Systox mot bladlöss har den största droppstorleken givit bäst resultat.

g) olika vätskemängder och preparatmängder har prövats, men vätskemängderna tycks ha varit utan nämnvärd betydelse, avgörande har varit den utsprutade mängden verksam substans.

6. Vid fältförsök med droppstorlekarna MMD 70 μ, 100 μ och 210 μ har följande resultat erhållits:

a) vid försök med DDT-preparat mot rapsbagge har bäst resultat erhållits med de båda mindre droppstorlekarna.

b) fältförsöken med parationpreparat har inte givit något resultat med avseende på bästa droppstorlek.

c) fältförsöken med Systox mot betbladlus har givit bäst resultat för den största droppstorleken.

7. Författaren diskuterar även metodiken vid fältförsöken och påpekar att vid de fortsatta fältförsök som är nödvändiga särskilt med parationpreparat och insekticider med systemverkan bör utom noggranna vanliga meteorologiska och ekologiska observationer även avdunstningen mätas med hjälp av en enkel avdunstningsmätare som med gott resultat prövats av författaren.

8. Försök med utsprutad NaCl-lösning i raps med samma droppstorlekar som i fältförsöken visar att största mängden saltlösning återfanns vid droppstorleken MMD 100 μ.
DDT-medlets bättre verkan vid denna droppstorlek kan alltså anses bero på att mängden verksam substans som fastnar på vegetationen blir störst vid denna droppstorlek. Som förklaring till detta kan anföras följande:

a) försöken med tillsats av fluorescerande substans till besprutningsmedlet antyder att droppstorleken 100 μ MMD fördelar sig jämnare i vertikal och horisontal led.

b) försöken med tillsats av fluorescerande substans visar också att dropparna inte så lätt flyter samman vid denna droppstorlek och att avrinningen följaktligen bör bli mindre, vilket även antyds av NaCl-försöket.

9. Att det bästa resultatet vid besprutningen med Systox uppnåtts med den största droppstorleken, 210 μ MMD, kan förklaras med detta ämnes stora flyktighet jämfört med de övriga insekticiderna. Försök med torkning av plantor i exsiccator och i fuktig kammare visar att skillnaderna till den största droppstorlekens fördel utjämnas vid torkning i fuktig luft (droppstorleken 100 μ har här givit störst antal döda insekter).
10. För att studera bekämpningsmedlens fördelning och avdrift har författaren använt fluorescerande substans som tillsats till besprutningsvätskan. Detta utgör ett värdefullt hjälpmedel då dropparnas fördelning direkt kan studeras eller fotograferas i ultraviolett ljus.

References

Andersson, R. F. 1948. Relation of Droplet Size to Toxicity in Residual-Type DDT-Oil Sprays. J. Econ. Ent. 41.

Ben-Amotz, Y. and Hoskins, W. M. 1937. Factors Concerned in the Deposits of Sprays. III. Effects of Wetting and Emulsifying Powers of Spreaders. J. Econ. Ent. 30.

Björling, K. and Sellgren, K. A. 1957. Protection and Its Connection with Redistribution of Different Droplet Sizes in Sprays against *Phytophtora infestans*. Ann. Royal Agric. Coll. Sweden 23.

Brooks, F. A. 1947. The Drifting of Poisonus Dusts Applied by Airplanes and Land Rigs. Agr. Eng. 28(6).

Brown, A. W. A. 1951. Insect Control by Chemicals. New York, Toronto and London.

Brown, G. T. and Hoskins, W. M. 1939. Factors Concerned in the deposits of Sprays. V. The Effect of pH upon the Deposit of the Oil and Water Phases of Oil Emulsions. J. Econ. Ent. 32.

Courshee, R. J., Daynes, F. K. and Byass, J. B. 1954. A Tree Spraying Machine. Nat. Inst. Agr. Eng. Report 36.

Fraser, R. P. and Eisenklam, P. 1953. Research into the Performance of Atomisers for Liquids. J. Imp. Coll. Chem. Eng. Soc. 7.

Frohberger, P. E. 1949. Untersuchungen über das Verhalten des Insektizids Diäthyl-p-nitrophenyl-thiophosphat (E 605) auf und in der Pflanze. Höfschen-Briefe 2.

Fuchs, N. 1937. Microscopic examination of fog, cloud and rain droplets. Nature 139.

Griffin, E. L., Richardson, C. H. and Burdette, R. C. 1927. Relation of size of oil drops to toxicity of petroleum-oil emulsions of aphids. J. Agr. Research 34.

Hellqvist, H. 1952. Besprutningstekniska problem vid användning av kemiska ogräsmedel. Växtodling 7.

Hoare, E. R. 1952. The World Spraying Problem. Farm Mechanization 4.

Hensill, G. S. and Hoskins, W. M. 1935. Factors Concerned in the Deposit of Sprays I. The Effect of Different Concentration of Wetting Agents. J. Econ. Ent. 28.

Klimke, A. and Haury, H. 1950. Die Atemgiftwirkung neuer insektizider Mittel. Anz. Schädlingsk. 23.

Latta, R., Andersson, L. D., Rogers, E. E., LaMer, V. K., Hochberg, S., Lauterbach, H. and Johnsson, I. 1947. The effect of particle size and velocity of movement of DDT aerosols in a wind tunnel on the mortality of mosquitoes. J. Wash. Acad. Sci. 37.

LaMer, V. K., Hochberg, S., Hodges, K., Wilson, I., Fales, J. A. and Latta, R., 1947. The Influence of the Particle Size of Homogenous Insecticidal Aerosols on the Mortality of Mosquitoes in Confined Athmospheres. J. Colloid. Sci. 2.

— 1951. Vad berättar en provningsredogörelse. Statens maskinprovningar. Meddelande 1000. Stockholm.

Potts, S. F. 1946. Particle Size of Insecticides and Its Relation to Application, Distribution and Deposit. J. Econ. Ent. 39.

Ripper, W. E. 1955. Application methods for crop protection chemicals. Ann. appl. Biol. 42.

Sharp, R. B. 1955. The Detection of Spray Deposits Using Fluorescent Tracers. Nat. Inst. Agr. Eng. no. 119.

Shepard, H. H. 1951. The Chemistry and Action of Insecticides. New York, Toronto and London.

Tansley, A. G. 1946. Introduction to Plant Ecology. London.

Tietz, H. 1954. Der mit ^{32}p markierte Diäthylthionophosphorsäureester des β-Oxyäthyl-thioäthyläthers (Wirkstoff des stystemischen Insektizides »Systox»), seine Aufnahme in die höhere Pflanze und sein Wanderungsvermögen. Höfchen-Briefe. 7.

Yeo, D. 1954. Aircraft Applications of Insecticides against Tsetse Flies and other Insect Pests in East Africa. Report of the Sixth Commonwealth Entomological Conference.

Yeoman, A. H. and Rogers, E. E. 1953. Factors Influencing Deposit of Spray Droplets. J. Econ. Ent. 46.

Yeoman, A. H., Rogers, E. E. and Ball, W. H. 1949. Behavior of Aerosol Droplets. J. Econ. Ent. 42.